Introduction

The desire to reduce emissions of greenhouse gas and particularly CO2 caused interest in energy efficient technologies in the production and compaction of asphalt mixtures [1, 5, 14, 16, 17]. For several years, studies are conducted on the use of various types of modifiers in order to obtain the right viscosity of the bitumen in the process of manufacturing asphalt mixtures at lower temperatures compared with traditional temperature, approximately 160–180°C [2, 3, 6, 11, 15]. Currently used classification of asphalt mixtures in terms of their manufacturing temperature is shown in Fig. 1.

![Fig. 1. Classification of asphalt mixtures by temperature range [1].](image)

Application of Warm Mix Asphalt technology allows manufacturing and compaction temperature of asphalt concrete to be decreased maximum of 40°C. However, unseeing foamed bitumen binder provide possibility of greater reduction in working temperature, about 60°C. In order to ensure the correct coating the mineral mix with foamed bitumen, seeks to improve foam performance, which are expansion ratio (ER) and half-life (t1/2) [4, 7, 8, 9, 12, 13, 18].

Tested materials

In the studies the asphalt concrete AC 22 was used, it was designed in according to the WT-2 [19] requirements. The 35/50 bitumen, synthetic FT wax, dolomite and devonian limestone aggregate and RAP was used in the mixture.

Bitumen

During studies asphalt 35/50 was used, which was subject to foaming. In order to improve it properties the synthetic FT wax was applied, which was dispensed into the binder in an amount of 3.0% before the foaming [10]. Tested binders foaming characteristics are shown in Fig. 2.
The use of synthetic FT wax in an amount of 3.0% in relation to the bitumen showed significant improvement of its characteristics. This should ensure the correct characteristics of the asphalt concrete produced with its participation.

**Mineral aggregate**

Mineral mixture of AC 22 W asphalt concrete was performed according to the WT-2 with local aggregate. The aggregate was obtained from Devonian dolomite and limestone from the Świętokrzyskie Mountains. Also a 15% asphalt granulate RAP which contained 6.0% asphalt, was used. RAP grain size is shown in Tab. 1.

**Table 1.** The sieve analysis of the reclaimed asphalt pavement

<table>
<thead>
<tr>
<th>RAP</th>
<th>Sieve analysis [mm]</th>
<th>&lt;0.063</th>
<th>0.063</th>
<th>0.125</th>
<th>0.25</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>5.6</th>
<th>8</th>
<th>11.2</th>
<th>16</th>
<th>22.4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>11.1</td>
<td>2.8</td>
<td>5.0</td>
<td>7.0</td>
<td>7.5</td>
<td>13.2</td>
<td>18.7</td>
<td>12.1</td>
<td>8.5</td>
<td>7.6</td>
<td>6.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Mineral mix frame composition of is shown in Tab 2.
Table 2. Frame composition of AC 22 W mineral mix

<table>
<thead>
<tr>
<th>Materials</th>
<th>MM [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolomite, granulated 16/22</td>
<td>15.0</td>
</tr>
<tr>
<td>Limestone, granulated 8/16</td>
<td>20.0</td>
</tr>
<tr>
<td>Limestone, granulated 2/8</td>
<td>20.0</td>
</tr>
<tr>
<td>Lime crushed sand 0/2</td>
<td>26.0</td>
</tr>
<tr>
<td>Reclaimed asphalt pavement (RAP)</td>
<td>15.0</td>
</tr>
<tr>
<td>Lime filler</td>
<td>4.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

In contrast, mineral mix design is shown in Fig. 3.

![Graph showing distribution of aggregate](image)

Fig. 3. Distribution of the aggregate used in AC22 W

Designed concrete contained 4.5% asphalt binder, which consisted 3.6% of asphalt 35/50 and 0.9% bitumen contained in RAP.

Results and discussion

To evaluate the effect of the foamed bitumen on the properties of the asphalt concrete in HWMA technology, the three types of mixtures was made:
- asphalt concrete with foamed bitumen marked as AC - C,
- asphalt concrete with foamed bitumen modified with synthetic FT wax marked as AC - CS
- traditional asphalt concrete (control) marked as AC - G.

As part of the research program adopted for comparative purposes the following parameters were determined asphalt concrete AC 22 W:
- air void contents $V_m$ according to PN-EN 12697-8,
water resistance ITSR according to PN-EN 12697-12 and WT2-2010 standards,
permanent deformation resistance of asphalt concrete, proportional rut development $WTS_{AIR}$ [mm/10$^3$ cycles] and $PRD_{AIR}$ is PN-EN 12697-22.

Water resistance of asphalt concrete was determined using the following formula:

$$ITSR = 100 \times \frac{ITS_w}{ITS_d}$$

where:
$ITS_w$ – the indirect tensile strength determined for the wet samples,
$ITS_d$ – the indirect tensile strength determined for the dry samples

The content of free space in investigated asphalt concretes and the characteristics of and their water resistance to is shown in Fig. 4.

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**Fig. 4.** Void fraction content $V_m$ (a) and water resistance – ITSR (b) of asphalt concrete
Based on the analysis of free space and water resistance the conclusion can be made that the influence of the technology on the characteristics of the asphalt concrete is significant. Conventional produce asphalt concrete was characterized by the most preferred parameters. The use of HWMA technology (AC-C) caused the increased content of free space of more than 2%, and decreased the water resistance. Asphalt concrete with foamed bitumen did not meet standards requirements. While the use of bitumen modification with FT wax before foaming caused a significant improvement in the investigated parameters of asphalt concrete AC-CS produced in HWMA technology. It can be argued that the effects of the FT wax on the properties of the asphalt concrete produced and paved in reduced temperatures was significantly.

![Graph of Permanent Deformation Resistance](image)

Fig. 5. Permanent deformation resistance of asphalt concrete AC 16 W in relation to production technique – proportional rut development WTS\textsubscript{AIR} [mm/10\textsuperscript{3} cycles] (a) and PRD\textsubscript{AIR} [%] (b)

When assessing the characteristics of permanent deformation resistance of asphalt concrete should be noted that a foamed bitumen modified with synthetic wax in an amount of 3.0% provided the best parameters in field of PRD\textsubscript{AIR} and WTS\textsubscript{AIR}. Asphalt concrete produced in the traditional technology AC-G was characterized by an approximated parameters. Whereas the used only foamed bitumen (AC-C) resulted
in a significant saucer in resistance on permanent deformation of asphalt concrete. The role of the FT synthetic wax is very significant because the difference in the characteristics values of permanent deformation resistance between the asphalt concrete AC-CS and AC-C is two times bigger. Therefore FT synthetic wax plays a very important structural role in bitumen binder and asphalt concrete. Fisher-Tropsh wax forms in the pavement in technological temperature range crystals, which plays a significant role in providing resistance to permanent deformation of asphalt concrete.

**Conclusion**

The following conclusions can be drawn from the study of the bitumen and bituminous mixtures:

- In the HWMA technology before preparation of asphalt mixtures in order to obtain asphalt concrete with the required properties, prior modification of bitumen with synthetic wax is required before foaming process;
- Application of 35/50 bitumen modified with FT synthetic wax added in an amount of 3.0% based on the weight of the binder provides a asphalt concrete in HWMA technology, assigned to the binding layer of pavement for regional traffic (KR4) that meets the criteria of WT 2;
- The HWMA concrete (AC-CS) with modified binder has greater resistance to permanent deformation than the asphalt concrete obtained in the technology "hot"(AC-G). Pavements made of (AC-CS) asphalt concrete involving will be more resistant to rutting than in a case where the conventional asphalt concrete (AC-G) has been used.

**Abstract**

In order to protect the environment, reduce greenhouse gas emission and improve the energy efficiency of the asphalt mixtures manufacturing process new technologies have been used. One of them is the Half Warm Mix Asphalt (HWMA) technology, wherein the foamed bitumen is used. The use of reclaimed asphalt pavement in the mineral mixture was also an important factor. In studies performed in order to improve the foaming characteristics of the bitumen (ER – maximum expansion, t1/2 – half-life of asphalt foam) the modification of bitumen with 2.5% synthetic Fisher-Tropsh (FT) wax was used. Asphalt concrete produced from this type of binder at temperatures up to 100°C was characterized by compared values of parameters (voids content, resistance to water ITSR, resistance to permanent deformation and PRD_{AIR} WTS_{AIR}) to the asphalt concrete produced in the traditional technology at temperature of 160°C.

**Keywords:** asphalt concrete, Half Warm Mix Asphalt technology, foamed bitumen, synthetic wax FT, RAP

**ZASTOSOWANIE DESTUKTU ASFALTOWEGO DO PRODUKCJI BETONU ASFALTOWEGO W TECHNOLOGII NA PÓŁCIEPŁO Z ASFALTEM SPIENIONYM**

**Streszczenie**

W celu ochrony środowiska, zmniejszenia emisji gazów cieplarnianych a zawłaszczają CO₂ oraz poprawy energetyczności procesu wytwarzania mieszanek mineralno-asfaltowych stosuje się nowe technologie. Jedną z nich jest technologia Half Warm Mix Asphalt (HWMA), w której wykorzystuje się asfalt spieniony. Istotnym elementem było również zastosowanie destruktu asfaltowego w składzie mieszanki mineralnej. W wykonanych badaniach w celu poprawy charakterystyk spieniania asfaltu (ER – maksymalnej ekspansji, t1/2 – czas połowicznego rozpadu piany asfaltowej) zastosowano wcześniej jego modyfikację za pomocą 2.5% wosku syntetycznego Fishera-Tropsha (FT). Wytworzony z tego rodzaju lepiszczem beton asfaltowy w temperaturze do 100°C charakteryzował się porównywanymi parametrami (zawartość wolnych przestrzeni, odporność na oddziaływanie wody ITSR, odporność na deformacje trwałe WTS_{AIR} i PRD_{AIR}) z betonem asfaltowym wytwarzanym w tradycyjnej technologii w temperaturze 160°C.
Słowa kluczowe: beton asfaltowy, technologia „na półciepło”, asfalt spieniony, wosk syntetyczny F-T, destrukt asfaltowy

References


