Impact of Additives on the Foamability of a Road Paving Bitumen

Mateusz M Iwanski¹, Anna Chomicz-Kowalska², Krzysztof Maciejewski²

¹Department of Building Engineering Technologies and Organization, Faculty of Civil Engineering and Architecture, Kielce University of Technology, Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland
²Department of Transportation Engineering, Faculty of Civil Engineering and Architecture, Kielce University of Technology, Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland
matiwanski@tu.kielce.pl

Abstract. Because of the needs for the increased efficiency and environmental concerns that now emerge environmentally friendly techniques are more sought for and more commonly utilized in the road paving industry. Typical asphalt mixes are produced in temperatures exceeding 150°C depending on the type of asphalt binder used, but new techniques are being developed, permitting decreased production and paving temperatures. One of the most effective techniques that are being studied are the Warm Mix Asphalt and Half Warm Mix Asphalt methods utilizing water based bitumen foaming that allow production of asphalt mixes at temperatures as low as 100°C. Due to the extremely low processing temperatures, it is often difficult to obtain satisfactory results regarding the physical and mechanical properties of the resulting mixes, specifically the resistance to moisture the damage and resistance to the permanent deformation being in concern. As these issues were found to be originating in the inadequate coating of aggregates, a surface active agent in amounts of 0,2% - 0,6% and synthetic wax in amounts of 1,0% - 2,5% were added to 50/70 paving bitumen to improve its foamability and coating potential. Foaming characteristics were established in terms of bitumen foam expansion ratio ER and its half-life HL as a function of foaming water content ranging from 1,5% to 4,0%. It was found that the addition of surface active agent in the amount of 0,6% resulted in the most favourable foam performance at 2,5% foaming water content, resulting in a doubling in expansion ratio and more than a 2,5 times increase in half-life compared to the base bitumen. It is believed that the improved foaming characteristics of the bitumen would significantly benefit the performance of a subsequent warm or half-warm asphalt mix.

1. Introduction
One of the main challenges faced by the industry is the reduction of greenhouse gas emissions and energy consumption of building materials manufacturing. This trend is also visible in road construction, in which traditional asphalt mixes are manufactured using the hot mix asphalt (HMA) technology, at the temp. of 170°C, depending on the type of asphalt used [1]. The main direction of related activities is, therefore, the reduction in manufacturing temperature, which is related to the reduction in emitting CO₂ and other harmful gases and manufacturing energy consumption.
Various types of additives are used for this purpose and their aim is to lower the asphalt’s viscosity, thereby allowing the asphalt mix manufacturing in temperatures lowered by approx. 30-40°C in relation to the traditional temperature resulting in the warm mix asphalt (WMA) technology [2]. The most commonly used additives include the Fisher-Tropsch synthetic wax [3]. Its use as an asphalt additive not only lowers the asphalt’s viscosity in the asphalt mix’s manufacturing and paving process temperature range [4], but also improves the rheological properties of the paving bitumen [5, 6] and the asphalt mix’s resistance to permanent deformation [7]. The use of the asphalt foaming technology using natural or artificial zeolite is also very important to reduce the asphalt mix manufacturing temperature [8, 9]. We can observe an intense growth of research concerning the development of new types of artificial zeolites ensuring the most favourable asphalt foaming performance [10]. Moreover, laboratory testing related to the use of various types of additives that can ensure obtaining a durable and cost-effective asphalt pavement is currently conducted [11].

The most substantial reduction in asphalt mix manufacturing temperature of approx. 70°C in comparison to the HMA technology is obtained by using water foamed asphalt [12, 13, 14]. Due to the significant reduction in asphalt mix’s manufacturing and incorporation process temperatures, the technology is called half warm mix asphalt (HWMA) [15, 16, 17].

The water foaming asphalt technology is developing dynamically from the beginning of the XXI century, when the possibilities of using it for modernising pavement structures in deep cold recycling were presented [16]. On the other hand, for over a dozen years it has been increasingly used to manufacture asphalt mixes using the HWMA technology [17, 18]. To ensure comparative properties in relation to the traditional asphalt mixes, it is necessary to use the best performing foamed asphalt. The asphalt is modified prior to foaming to obtain its high parameters. The F-T synthetic wax is can be used for this purpose [4, 7]. Unfortunately, the use of this type of modifier limits the reduction in asphalt mix’s compaction temperature, because in the temp. of 90°C the F-T synthetic wax solidifies in the paving bitumen in the form of crystallites. Due to the above, the compaction process is very difficult. Additionally, due to the low ambient temperatures in early spring and late autumn, the use of synthetic wax modification can result in problems with asphalt mix’s compaction. Other types of asphalt additives are therefore sought, the use of which will ensure obtaining high foaming parameters and thereby ensure sufficient asphalt mix quality and contribute to the extension of the road season. Due to the above, a surface active agent (surfactant) was used in testing as an asphalt additive before foaming.

2. Tested materials and methodology
2.1. Experimental program
The purpose of the testing program was to determine the impact of the F-T synthetic wax and surface active agent on the 50/70 asphalt foaming parameters. The testing of asphalt foaming was conducted using the WLB-10 S special laboratory foaming device presented in figure 1.
Figure 1. WLB 10 S laboratory foaming device

The determination of the 50/70 asphalt (with additives) foaming parameters was conducted according to the developed recommendations [19]. The conceptual representation of the asphalt foaming is presented in figure 2.

Figure 2. Conceptual representation of the asphalt foaming [20]

The following parameters were determined during the asphalt foaming process [19, 21]:
- maximum expansion ER,
- asphalt foam half-life HL [s],
- foaming water content for obtaining the optimal parameters of ER and HL – FWC [%].

Due to the fact, that the asphalt foaming parameters play a significant role in the manufacturing process of asphalt mix obtained in the HWMA technology, thereby ensuring its required durability, these features were adopted as the basic criteria for the paving bitumen’s usefulness. Due to the above, the 50/70 asphalt testing was conducted and the impact of the surface active agent (0.2%, 0.4% and 0.6 % in relation to the paving bitumen’s weight) and the F-T synthetic wax (1.0%, 1.5%, 2.0%, 2.5 % in relation to the asphalt’s weight) on the paving bitumen’s foaming features in terms of concentration was determined. Then, the paving bitumen’s composition characterised by the most favourable foaming parameters (ER, HL) at the specific foaming water content FWC (%) was selected.

2.2. Materials
The testing featured the 50/70 asphalt and additives affecting the foaming process – the F-T synthetic wax and a surface active agent. The basic properties of the 50/70 asphalt are presented in table 1.

| Property                      | Testing method | Unit   | Value |
|-------------------------------|----------------|--------|-------|
| Penetration in 25˚C           | EN 1426        | 0.1 mm | 65.9  |
| Softening point (R&B)         | EN 1427        | °C     | 50.4  |
| Fraass breaking point         | EN 12593       | °C     | -15.1 |
| Dynamic viscosity:            |                |        |       |
| 60˚C                          | EN 12702-2     | Pa·s   | 372.9 |
| 90˚C                          |                | 14.0   |
| 135˚C                         |                | 0.649  |

The material properties of the F-T synthetic wax are presented in table 2 and of the surface active agent - in table 3.

| Property                  | Unit | Value  |
|---------------------------|------|--------|
| Colour                    | -    | white, yellowish |
| Flash point               | °C   | 285    |
| Solidifying point         | °C   | 95     |
| Density at 25 ˚C          | Mg/m³| 0.9    |
| Viscosity at 135 ˚C       | Pa·s | 12     |
| Molecular mass            | g/mol| ca. 1000 |

| Property                  | Unit | Value  |
|---------------------------|------|--------|
| Appearance                | -    | brown liquid |
| Flowing point             | °C   | < 0    |
| Viscosity at 20°C         | mP   | 3000   |
| Viscosity at 50°C         | cP   | 400    |
| Amine number              | mg HCl/g | 159 - 185 |
| Acid number               | mg KOH/g | < 10  |
| Solidifying point         | °C   | < 0    |
| Flash point               | °C   | >218   |
3. Test results and analysis

The 50/70 asphalt foaming properties as average values from 9 designations are presented in figure 3.

![Figure 3](image)

**Figure 3.** Foaming characteristics of the 50/70 road paving bitumen

Then, the impact of the F-T synthetic wax on the ER maximum expansion and the HL foam half-life of 50/70 asphalt was tested. The F-T synthetic wax was used in the amounts of 1.0%, 1.5%, 2.0% and 2.5% in relation to the paving bitumen’s weight. The test results are presented in figure 4.

![Figure 4](image)
When analysing the obtained 50/70 asphalt foaming properties in terms of the quantity of F-T synthetic wax additive used, it is possible to clearly ascertain its positive impact. The increase in concentration of the F-T synthetic wax was associated with an increase in the paving bitumen’s maximum expansion and asphalt foam’s half-life. Due to the above, such a paving bitumen would coat aggregate grains more effectively during the asphalt mix manufacturing.

For comparative purposes of obtaining the most favourable features of the 50/70 asphalt foaming, a surface active agent (Wetfix BE) was used and dosed in the amounts of 0.2%, 0.4% and 0.6% in relation to the bitumen’s weight. The maximum quantity of the dosed surface active agent was adopted as 0.6% in relation to the asphalt’s weight, because it is the limit value recommended by the manufacturer for its use in hot and cold mix asphalt technologies. The results of testing the 50/70 asphalt foaming properties in terms of the surface active agent quantity are presented in figure 5.

**Figure 4.** Bitumen foaming characteristics 50/70 + 1.0% F-T (a), 50/70 + 1.5% F-T (b), 50/70 + 2.0% F-T (c) and 50/70 + 2.50% F-T (d)
Figure 5. Bitumen foaming characteristics 50/70 + 0,2% surfactant (a), 50/70 + 0,4% surfactant (b), 50/70 + 0,6% surfactant (c).

The average values of the 50/70 asphalt foaming properties at optimum foaming water contents in terms of the type and quantity of the used additive are presented in table 4 and graphically in figure 6.

Table 4. The foaming properties of the 50/70 bitumen in terms of the type and quantity of the used additive at the designated optimum foaming water content

| Binder designation | Binder type | ER | HL [%] | FWC [%] |
|--------------------|-------------|----|--------|---------|
| A0                 | 50/70       | 10 | 8      | 2,5     |
| A1                 | 50/70 + 1,0% F-T | 12 | 11     | 2,5     |
| A2                 | 50/70 + 1,5% F-T | 14 | 12     | 2,5     |
| A3                 | 50/70 + 2,0% F-T | 15 | 13     | 2,5     |
| A4                 | 50/70 + 2,5% F-T | 18 | 15     | 2,0     |
| A5                 | 50/70 + 0,2% W | 12 | 10     | 2,5     |
| A6                 | 50/70 + 0,4% W | 17 | 14     | 2,5     |
| A7                 | 50/70 + 0,6% W | 19 | 21     | 2,5     |
Based on the conducted analysis of the test results, it is possible to state that both the F-T synthetic wax and the surface active agent had a positive impact on the improvement of the 50/70 asphalt foaming properties. The intensity of changes in the ER maximum expansion and the HL asphalt foam half-life depends on the quantity of the dosed additive and increases along with its concentration in the paving bitumen. The most favourable 50/70 asphalt foaming properties were obtained when using 0.6% of the surface active agent in relation to the asphalt’s weight. The ER maximum expansion of the 50/70 asphalt increased nearly twice and the HL asphalt foam half-life increased two-and-a-half times. It is also worth noting that the paving bitumen’s maximum expansion ratio with the use of 2.5% of the F-T synthetic wax in asphalt is comparable to the expansion obtained in the case of using 0.6% of the surface active agent. On the other hand, the asphalt foam half-life is approx. 30% higher than in the case of using the surface active agent.

The most favourable foaming parameters were demonstrated by the 50/70 asphalt with an addition of 0.6% of the surface active agent, which was characterised by the following properties: ER – 19, HL – 21 and FWC – 2.5%.

4. Conclusions
An analysis of the test results leads to the following conclusions:

- the use of asphalt additives in the form of the F-T synthetic wax and a surface active agent had a positive impact on the features of the foamed asphalt – the ER maximum expansion and the HL asphalt foam half-life,
- an increase of the quantity of the F-T synthetic wax to 2.5% of asphalt and of the surface active agent to 0.6% of asphalt caused an improvement in the foamed asphalt properties,
- the use of the F-T synthetic wax in the amount of 2.5% in the 50/70 asphalt caused a nearly double increase in its foaming features when using 2.0% of water (FWC) in the foaming process,
- the addition of 0.6% of the surface active agent caused a nearly double increase in the ER maximum expansion and nearly a triple increase in the HL half-life of the 50/70 half-life when using 2.5% of foaming water content.
the addition of the F-T synthetic wax in the amount of 2.5% and the surface active agent in the amount of 0.6% resulted in a comparable ER maximum expansion of the 50/70 foamed asphalt, but the HL foam half-life in the case of using the surface active agent was approx. 30% higher than when using the F-T synthetic wax.

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