Effect of WMA Additives on Asphalt Ageing - Case Study

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Abstract

One of the current main trends in road construction is striving to ensure greater durability of asphalt surfaces. The observed increase in road traffic, especially the increase in heavy goods vehicles in the overall traffic structure, as well as the impact of adverse weather conditions such as prolonged high summer temperatures and low winter temperatures, and the impact of rain and snowfall contribute to reducing the durability of asphalt surfaces. An important material factor that also affects the reduction of the durability of asphalt surfaces is the ageing of asphalt. In the process of rolling the mineral-asphalt mixture, it is affected by elevated temperatures ranging from 165oC to even 200oC, which contributes to the loss of the adhesive-elastic properties of the asphalt. This process intensifies during the exfoliation of the asphalt surface, which is affected by solar radiation and atmospheric waste. To counteract asphalt ageing, work is conducted to modify it using, for example, polymers and various chemical additives, as well as the use of technologies in which asphalt can be used to produce mineral-asphalt mixture at a reduced temperature. The most effective solutions of this type include the technology of water-foamed asphalt. To limit the ageing of 50/70 asphalt in tests, synthetic wax was used as an additive dosed at 1.0%, 1.5%, 2.0% and 2.5% by weight, and a surfactant was used at 0.2%, 0.4% and 0.6% by weight in relation to the asphalt. Studies on the impact of additives on road asphalt 50/70 before and after the water foaming process have been conducted. The change in basic asphalt parameters after RTFOT technological ageing was analysed. A significant impact of additives on the ageing process of 50/70 asphalt has been observed. Synthetic wax has a more intense effect on asphalt 50/70, it slows down the aging of the binder more than the use of a surface-active agent. On the other hand, the use of additives to asphalt 50/70 before its foaming with water has an even more beneficial effect on slowing down the intensity of binder ageing. In summary, the use of synthetic wax and a surfactant as additives to asphalt treated with foamed water will not only help limit the ageing of the binder and ensure the durability of the asphalt surface, but will also play a significant role in producing more environmentally friendly mineral asphalt mixes as a result of lowering the technological temperatures of their production process.

Keywords: *asphalt, technological ageing, synthetic wax, surface-active agent*

1. Introduction

Currently, road construction faces many technological challenges related to ensuring driving comfort and durability of the pavement structure, as well as concerns about environmental protection. Asphalt surfaces during operation are subject to the influence of ageing destructive factors, which include the constantly increasing load on the structure due to the ever-increasing vehicle traffic, especially the increase in the overall structure of heavy vehicle traffic. It is also important to consider such environmental factors as solar radiation, low winter, and high summer temperatures, as well as atmospheric precipitation. The intensity of the impact of these factors on the asphalt surface also depends on the changes occurring in the mineral-asphalt mix, especially around the binder which undergoes ageing. During the transportation, storage, and production process of mineral-asphalt mixture, it is subjected to elevated temperatures ranging from 165oC up to even 200oC, which contributes to the loss of sticky-elastic properties of asphalt. This phenomenon intensifies, as mentioned earlier, during the exfoliation of asphalt pavement. Aging associated with the impact of high technological temperatures in the production process affecting asphalt is simulated in laboratory conditions using the RTFOT methodology. One of the first methods to limit the ageing of asphalt was the addition of hydrated lime to the mineral-asphalt mix [1-4], which also improved its water and frost resistance, as well as improved resistance to permanent deformation. Currently, technologies are being developed to limit the ageing of asphalt, characterised by lower technological temperatures compared to traditional technology [5-7]. Reducing the temperatures of mineral-asphalt mixtures, in addition to the aspect of limiting asphalt ageing, also plays a significant role in reducing the “greenhouse” effect of industrial human activity resulting from reducing the energy consumption of technological processes. They also influence the improvement of working conditions for workers involved in the production process and then embedding the mineral-asphalt in the layers of the pavement construction. As a result of reducing the temperature gradient between the energy-efficient mineral-asphalt mix and the environment, the roadworks season is also extended.

In road construction, one of the most energy-intensive processes is the production of mineral-asphalt mixture intended for the upper layers of the pavement structure, the temperature of which, depending on the type of asphalt, can even reach up to 220oC. To limit such elevated temperatures in the production process, WMA (Warm Mix Asphalt) technology is implemented, in which special additives are used to reduce the viscosity of asphalt [8-9] or asphalt foamed with zeolite [10-11]. It allows to produce mineral-asphalt mixture at a temperature of about 135oC [12]. However, the most energy-efficient and effective is the HWMA (Half Warm Mix Asphalt) technology, in which water-foamed asphalt is used [13- 14]. It is characterized by two parameters, i.e. maximum expansion - ER (Maximum Expansion Ratio) and half-life of asphalt foam HL (Half-life) [15]. Using this type of technology allows it to lower the technological temperature of the production of mineral-asphalt mixture even down to 110oC. In the initial implementation period, water-foamed asphalt was only used in the technology of deep cold recycling of pavement structures [16- 17]. The increase in interest in global road construction in energy-saving technologies has led to research work on the use of foamed asphalt for mineral-asphalt mixtures used for the top layers of pavement structures [18- 19]. To achieve such mixtures meeting the standard requirements and having comparable or higher properties than traditional mineral-asphalt mixtures, the aim is to obtain foamed asphalt with the highest possible foaming parameters. Achieving such an effect requires the use of distinct types of asphalt additives before its foaming. The most used include synthetic F-T wax [20-22] and chemical additives, among them surfactants [23]. One type of asphalt additive was most used. However, the interaction of additives, apart from the beneficial increase in asphalt foaming characteristics, can also affect its properties or the properties of the mineral-asphalt mixture in a less favourable way in certain cases. An example may be synthetic wax, which, in the range of technological temperatures of the production of mineral-asphalt mixture, lowers the production temperature, however below a temperature of about 90oC may complicate the densification of this type of material [24]. However, in terms of the operating temperatures of the surface, it appears in the form of crystals strengthening its structure, thereby improving resistance to permanent deformation [24]. However, surface-active agents, like synthetic wax, during the production of mineral-asphalt mix reduce the viscosity of asphalt, affecting the lowering of its production temperature, and during the compaction process, no undesirable effect is observed. Therefore, to implement them for use in road construction, it is essential to conduct tests on the impact of additives on the properties of asphalt before and after foaming, taking into account ageing.

2. Materials and Research Program

2.1 Tested Materials

In the studies, asphalt 50/70 was used, which is commonly used in Central and Eastern European countries to produce mineral-asphalt mixtures intended for the upper layers of asphalt road construction. In the basic values of this binder are presented in table 1.

Tab. 1. Basic properties of 50/70 bitumen.

Property	**Test Method**	**Unit of Measurement**	**Result**
Penetration at 25°C	EN 1426	0.1 mm	65.9
Softening point TR&B	EN 1427	°C	50.4
Fraass breaking point	EN 12593	°C	-15.1

As additives to asphalt, a surface-active agent SAA with a liquid consistency was used, as well as synthetic wax F-TLC, which occurs in solid form in the form of small granules (Figure 1)

(a) (b)

Fig. 1. Chemical additives used for foaming of asphalt 50/70: surface active substance (a) and synthetic wax F-TLC (b).

The properties of synthetic F-T waxLC and surface-active agent SAA are outlined in table 2 and table 3.

Tab. 2. Characteristics of the synthetic wax F-TLC.[25]

Property	**Unit of Measurement**	**Value**
Colour	-	white, yellowish
Flash point	oC	285
Freezing temperature	oC	95
Density at 25 oC	Mg/m3	0.9
Viscosity at 135 oC	Belt	12
Molecular weight	g/mol	approx. 1000

The synthetic wax F-TLC used in research is characterised by a reduced "carbon footprint" compared to those previously used in road practice [25].

Tab. 3. Characteristics of the surface-active agent SAA [26].

Property	Unit of Measurement	Value
Appearance	-	Brown viscous liquid
Density at 20°C	Mg/m3	0.88-0.98
Viscosity at 20°C	mP	3000
Freezing point	°C	<0
Flash point (open flame)	°C	>218

In the studies, particular attention was paid to achieving the uniformity of the binder after adding the 50/70 asphalt additive. Therefore, the proper preparation of laboratory samples was significant in order to meet this condition. To a sample of adhesive with a mass of 1000 g, synthetic F-T waxLC was added. The process of mixing the binder with an additive involved heating the binder to a temperature 100oC higher than its softening temperature and mixing it in a blender at this temperature using a stirrer rotating at speeds of 150 revolutions/min for 30s, and then at a speed of 600 revolutions/min for 270s. To obtain analytical samples for testing, the procedure was followed in accordance with EN 12594 standard. Then a macroscopic assessment of the obtained binder samples was performed. When a lack of uniform colour of the binder was observed or the presence of distinct types of spots on the surface of the analytical sample indicating improper dissolution of the synthetic F-T waxLC such samples were not used in the studies. In a comparable way, the procedure was followed to apply the surface-active agent to asphalt 50/70.

2.2 Experimental program

The scope of the investigation into the impact of SAA and synthetic F-T waxLC dosed to the binder covered three stages. As part of the first stage, the impact of chemical additives on the basic properties of the binder before foaming was investigated:

- penetration at 25°C temperature (Pen, EN 1426:2015-08),
- softening temperature (TR&B, EN 1427:2015-08),
- Fraass breaking point temperature (TFraass, EN 12593:2015-080.

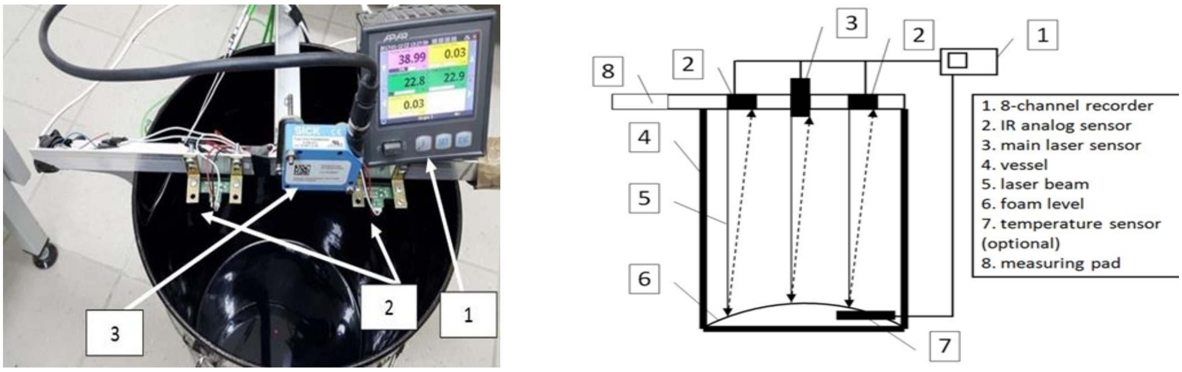
The second stage of the research involved determining the foaming characteristics of the binder, which are:

- maximum ER expansion [15],
- half-life of asphalt foam HL [15].

The marking of asphalt foam foaming parameters was conducted with the amount of foaming water FWC (Foaming Water Content) in the range of 1.5%, 2.0%, 2.5% and 3.0%, using the WLB-10S research station for this purpose, in accordance with recommendations [17] (Figure 2).

Fig. 2. WLB-10S test stand for the production of foamed asphalt [21]

On the other hand, the asphalt foaming parameters were determined using a measurement method developed at the Kielce University of Technology [27]. The measuring device is presented in Figure 3.



(a) (b)

Fig. 3. Measurement position of asphalt foaming parameters (1 - recorder, 2 - auxiliary analogue distance sensors with infrared spectrum, 3- laser sensor): perspective photograph (a); measuring device scheme (b) [27]

The third stage of the research focused on the impact of ageing procedures (RTFOT EN 12607-1:2014-12) on the properties of 50/70 asphalt with the addition of synthetic F-TLC wax and 50/70 asphalt with the addition of a surface-active agent before and after foaming the modified asphalt.

3. Results and Discussion

The foaming tests of 50/70 asphalt with the addition of F-T synthetic waxLC and surface-active agent were performed on nine research samples [28]. These allowed for the preparation of foaming characteristics, based on which basic foaming parameters were determined, the average values of which are presented in Figure 4 and Figure 5.

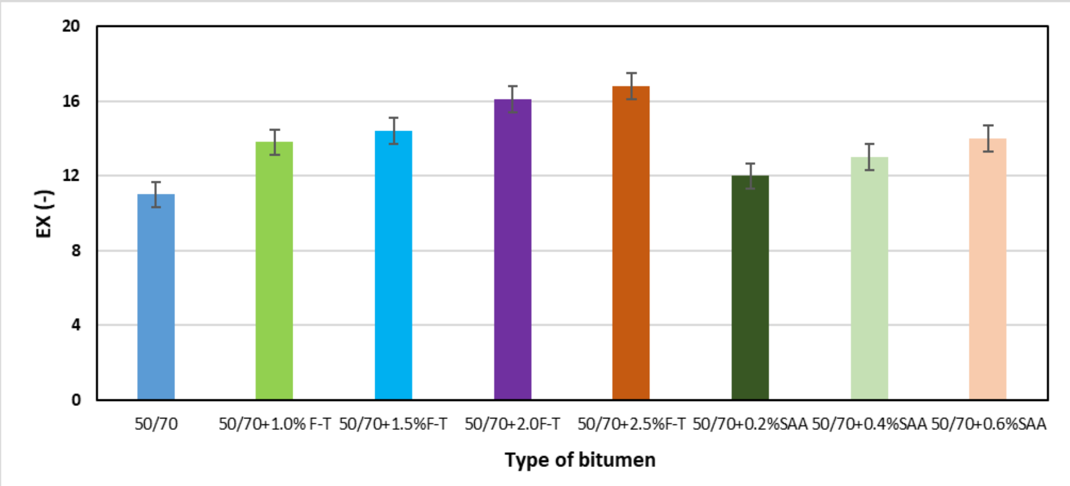


Fig. 4. The impact of synthetic F-T waxLC and SAA on the maximum expansion of foamed asphalt 50/70

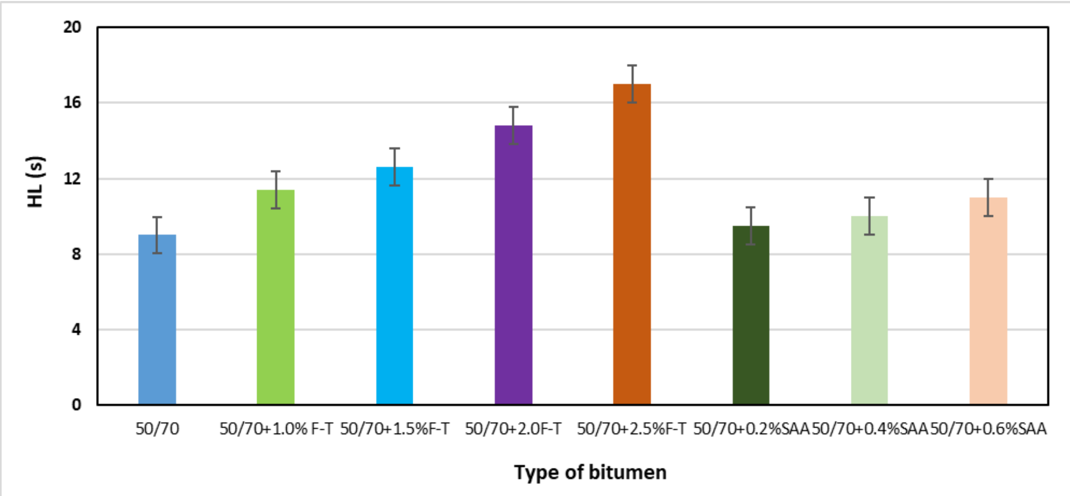


Fig. 5. The influence of synthetic F-T waxLC and SAA on the half-life of HL foamed asphalt foam of foamed asphalt 50/70

Based on the obtained results of the asphalt 50/70 foaming tests, it can be stated that the additives used have an impact on its foaming parameters, causing their increase. The synthetic wax F-TLC has a greater impact on the growth of maximum ER expansion and the half-foaming time of HL-modified binder than the surface-active agent PAS. With the compaction of synthetic F-TLC wax, just 1.5% resulted in an increase in foaming characteristics by over 50%.

The application of foamed asphalt with the addition of F-T synthetic waxLC and the surface-active agent PAS will play a beneficial role in surrounding the aggregate of the mineral-asphalt mixture, thereby influencing the achievement of its physical-mechanical parameters at a high-quality level.

The next stage of the research involved assessing the impact of WMA additives on the parameters of 50/70 asphalt before and after foaming, considering RTFOT ageing. The change in penetration at 25oC in 50/70 asphalt before and after foaming is shown in Figure 6.

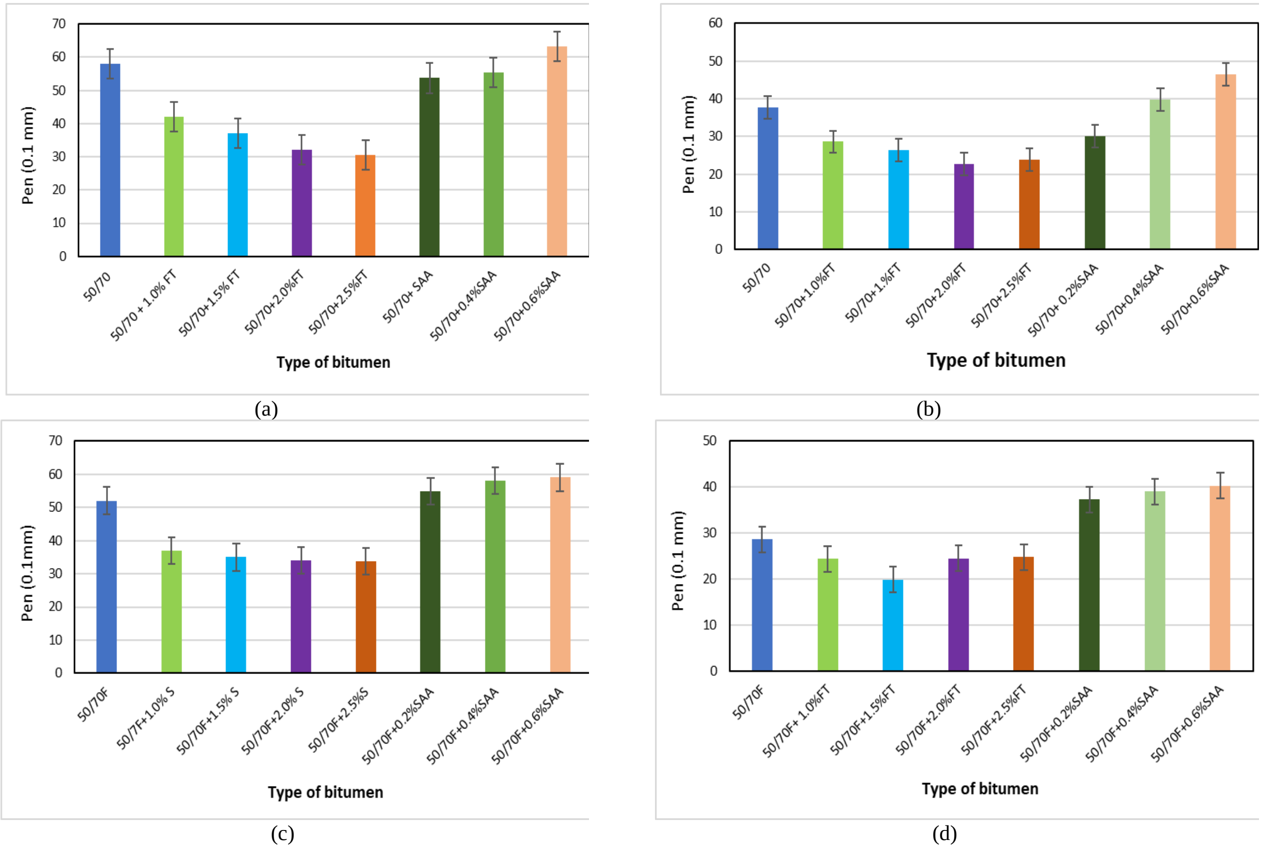


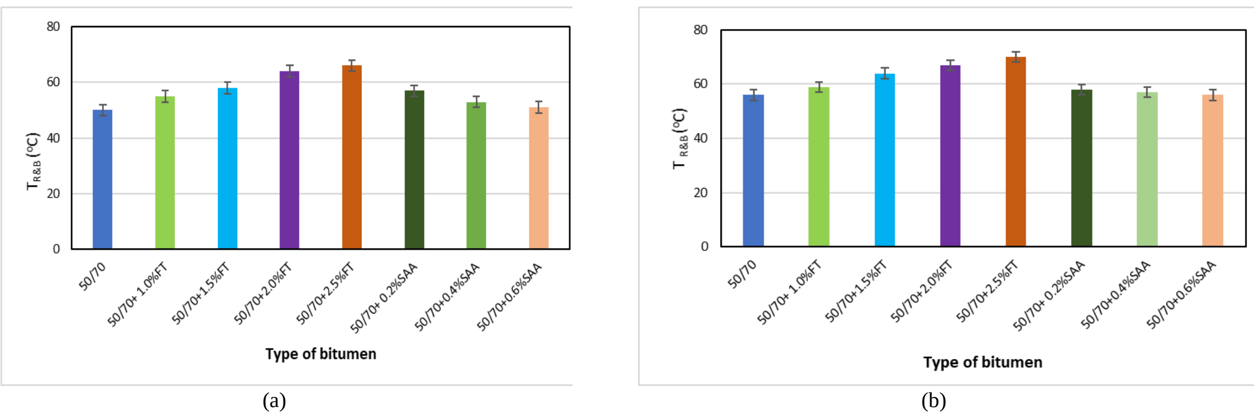
Fig. 6. The impact of WMA additives on the penetration of 50/70 asphalt; asphalt before foaming (a), asphalt before foaming after RTFOT ageing (b), asphalt after foaming (c), asphalt after foaming and RTFOT ageing (d)

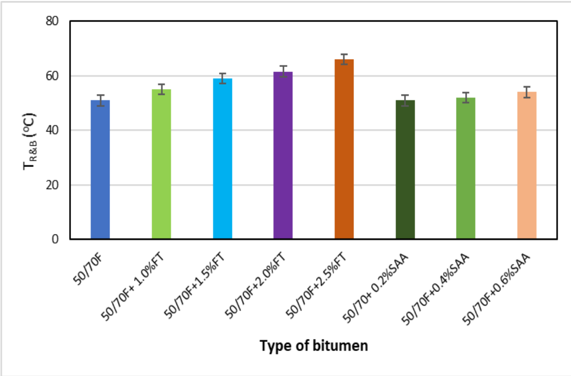
Based on the analysis of the results presented in Figure 6, it can be stated that the synthetic wax F-TLC affects the reduction of penetration of 50/70 asphalt not subjected to foaming. The binder structure is being strengthened. With the compactness of synthetic F-TLC wax in the amount of 2.5%, the penetration of this binder is 50% less than the control asphalt 50/70. The SAA's impact on the penetration of 50/70 asphalt is significantly less intense and at a density of 0.4%, the binder's penetration is already greater than that of the control 50/70 asphalt.

RTFOT ageing affects the reduction of 50/70 asphalt penetration. A similar relationship is observed in the case of substituting WMA additives. With the tendency of their interaction preserved as for asphalt 50/70 not subjected to ageing.

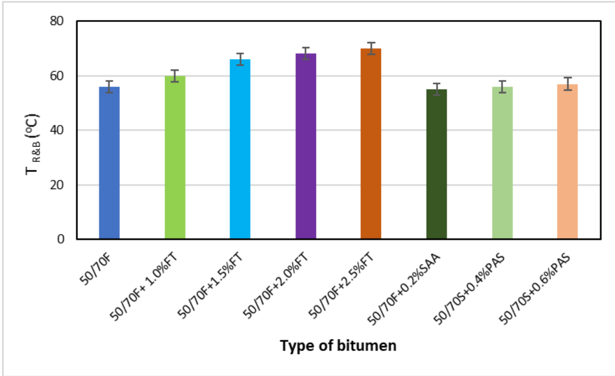
Foaming asphalt 50/70 causes an insignificant reduction in the penetration of asphalt 50/70 compared to the binder before foaming. Substituting synthetic wax F-TLC affects the penetration of foamed asphalt 50/70 application as in the case before its foaming. However, SAA causes an increase in the penetration of foamed binder, and it is higher than for the control asphalt 50/70. After RTFOT ageing, a reduction in the penetration of 50/70 asphalt by approximately 20% is observed compared to unaged binder. In the case of using WMA additives, a similar trend of their impact on the RTFOT aged binder penetration is observed as before aging.

The next parameter analysed is the change in the softening temperature of the 50/70 asphalt before and after foaming, considering RTFOT ageing, as presented in Figure 7.





(c)



(d)

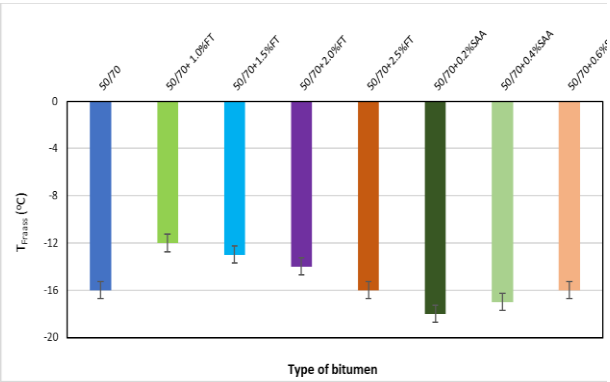
Fig. 7. The influence of WMA additives on the softening temperature of 50/70 asphalt; asphalt before foaming (a), asphalt before foaming after RTFOT aging (b), foamed asphalt (C), foamed asphalt after RTFOT aging (d)

Based on the analysis of the results of the study presented in Figure 7, it can be concluded that the synthetic wax F-TLC significantly affects the increase in softening temperature of unfoamed asphalt 50/70, which, as mentioned earlier, is the result of its stiffening role in the binder. The use of synthetic wax F-TLC in the amount of 2.5% causes an increase in the softening temperature of the binder by virtually 25% compared to control asphalt 50/70. The SAA's impact on the softening temperature of asphalt 50/70 is significantly less intense. With an SAA content of 0.4%, the binder softening temperature is comparable to the softening temperature of control asphalt 50/70. Increasing the SAA density in the binder continues this trend.

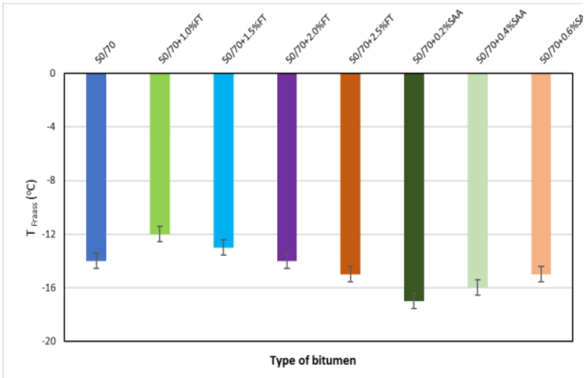
RTFOT ageing insignificantly affects the change in the softening temperature of 50/70 asphalt, which slightly increases compared to the softening temperature of 50/70 asphalt before ageing. When using WMA additives, the same trend in their effect on the softening temperature is observed as with asphalt 50/70 before ageing.

Foaming asphalt 50/70 causes a minor increase in the temperature of the asphalt 50/70 foaming compared to the binder before foaming. The synthetic wax F-TLC affects the softening temperature of foamed asphalt 50/70 application as in the case before its foaming, the tendency of its interaction with the binder is the same. On the other hand, the application of SAA has the opposite effect than in the case of non-foamed asphalt 50/70. In the entire range of SAA application, the softening temperature value is comparable to the softening temperature of asphalt50/70. The RTFOT ageing effect does not change the nature of the WMA additives' impact on the softening temperature of 50/70 asphalt. The same trend of their interaction with the binder is maintained as after foaming and before scorching.

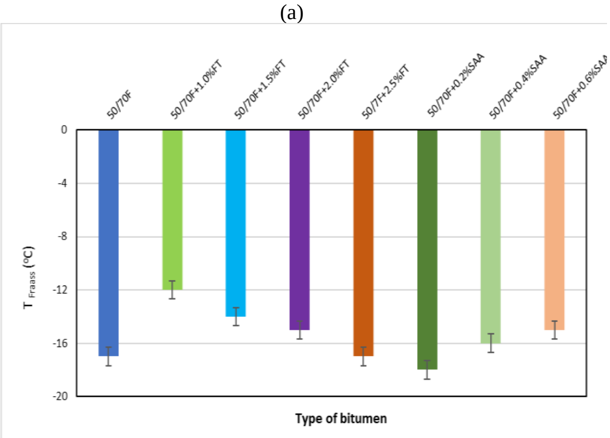
The next parameter subjected to analysis is the change in Fraass temperature of 50/70 asphalt before and after foaming, considering RTFOT ageing, which is presented in Figure 8.



(a)



(b)



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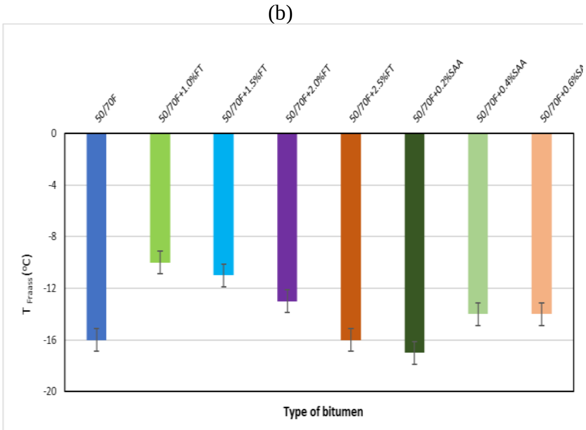

(d)

Fig. 8. Impact of WMA additives on the Fraass temperature of asphalt 50/70; asphalt before foaming (a), asphalt before foaming after RTFOT aging (b), asphalt after foaming (c), asphalt after foaming and RTFOT aging (d)

Based on the analysis of the results of the tests presented in Figure 8, it can be concluded that the synthetic wax F-TLC has a less favourable impact on the Fraass brittleness temperature both for 50/70 asphalt before and after foaming as well as RTFOT ageing. However, the interaction of SAA throughout the entire range of the experiment is beneficial. Therefore, the combined use of these two WMA additives may significantly positively affect the Frassa asphalt 50/70 temperature across the entire research range.

4. Conclusion

Based on the analysis of the conducted studies, the following conclusions can be drawn:

The intensity of the WMA additives' impact on the foaming characteristics of asphalt 50/70 is varied. The synthetic wax F-TLC significantly influences the improvement of the ER expansion index and the HL half-life of foamed asphalt as its concentration in the binder increases. However, the SAA interaction is of little significance to the analysed characteristics of 50/70 asphalt foaming,

The application of synthetic wax F-TLC has a stiffening effect on the properties of 50/70 asphalt, improving its penetration at 25oC, softening temperature and Fraass. However, SAA has negligible impact on the change of the analysed characteristics of asphalt 50/70. As its concentration in the binder increases, the rate of change in penetration at 25oC, softening temperature and Fraass slows down,

after RTFOT ageing, the influence of WMA additives shows the same tendency to change the analysed parameters of asphalt 50/70 as before ageing,

the foaming process of asphalt 50/70 causes a minor change in binder properties, the trend of WMA additives interaction on penetration changes at 25oC, softening temperature and Fraass remains,

WMA additives after RTFOT ageing of foamed asphalt 50/70 act in an equivalent way as before its foaming on the analysed properties of the binder,

The analysis of the impact of F-T synthetic waxLC and SAA on the properties of asphalt before and after foaming indicates that the application of both additives to the 50/70 asphalt in a specific concentration as a result of synergy can have a very beneficial effect both on the properties of the binder after foaming and taking into account its RTFOT ageing.

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