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Moisture resistance and compactibility of asphalt concrete produced in half-warm mix asphalt technology with foamed bitumen

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HIGHLIGHTS

- We evaluated a fine asphalt concrete mix with foamed bitumen compacted at 95 °C.
- The foam mix with 2.5% Fischer-Tropsch wax performed similarly to HMA.
- Moisture resistance testing procedure was significant to obtained results.
- The air void content had an effect on all of the measured properties of the mixes.

GRAPHICAL ABSTRACT

AC 8 Asphalt concrete	Air Voids 2x75 Marshall	ITSR (-18°C ➡ 60°C)	ITSR (-18°C ➡ 25°C)
Mix A: HMA compaction @ **140°C**	2.11%	97%	106%
Mix B: FB compaction @ **95°C**	3.38%	86%	92%
Mix C: FB + FT wax compaction @ **95°C**	2.29%	93%	101%

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ABSTRACT

Current regulations regarding emissions, as well as the efforts focused on reducing energy intensity of building materials production create a need for implementing new road construction technologies. Particular attention is being paid to the lowering of asphalt concrete production temperature, which is about 160 °C. In response to this need warm mix asphalt (WMA) technologies have been developed which allow producing asphalt mixes at temperatures about 20–30 °C lower than those of conventional methods. However, it was only after half warm mix asphalt (HWMA) was introduced that the mixing temperature of asphalt concrete with foamed bitumen could be reduced by as much as 60 °C. Asphalt pavements constructed with HWMA may have a reduced service life and lower resistance to environmental factors (e.g. water). This paper presents the results from the tests with one freeze cycle and from the moisture sensitivity analysis conducted for the low-temperature asphalt concrete (AC 8) with foamed bitumen and the control mix produced according to conventional hot mix asphalt technology. It was found that the modification of 50/70 bitumen (before foaming) with the addition of 2.5% *FT* synthetic wax had a beneficial effect on the properties of asphalt concrete mixes under investigation. The *ITSR* indices were compared having been determined in accordance with procedures based on European and AASHTO standards that are widely used in Poland. The analysis was extended to include the compactibility evaluation of low-temperature bituminous mixes and the impact of air voids on the mechanical parameters. The foamed asphalt concrete modified with 2.5% *FT* wax was found to satisfy the requirements for moisture resistance determined during the test with one freeze cycle.

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1. Introduction

The reduction in energy intensity of technological processes and the lowering of greenhouse gas emissions produced during these processes are the key element of the environmental protection policy. In the road paving industry, HMA (Hot Mix Asphalt) mixtures production is one of such processes. HMA mixtures are manufactured at temperatures of about 170–180 °C, depending on the type of bitumen used. The use of low viscosity modifiers, such as Fischer-Tropsch (FT) synthetic wax, allows production and placement of mixtures at temperatures about 20–30 °C lower [1], with a beneficial effect on the change in rheological characteristics of binders [2]. The reduction in energy required to produce a mineral-bitumen mix with Fischer-Tropsch wax is similar to that coming from the incorporation of reclaimed asphalt pavement in the mix [3]. These eco-friendly mixtures, which are produced in WMA (warm mix asphalt) technology require that aggregates making over 90% of the mixture composition, have to be subjected to the same thermal treatment as in the standard hot mix technology as this is the only way to remove a thin water film from the aggregate surface. The water has to be removed to ensure proper adhesion between bitumen and the aggregate surface, thus providing the mixture with adequate resistance to moisture – the most deleterious factor affecting road pavement quality [4]. The effect of water on bituminous mixtures (and asphalt pavements) is complex and dependent on several factors, which include aggregate type [5,6], bitumen type [7,8], adhesion promoters and bitumen ageing retarders [8–10]. They all have a substantial influence on the thickness of the binder film forming on the aggregate particles [11]. A significant part is also played by the structure of the pavement layer, characterized by air void content [12] dependent on the compaction temperature. Production and paving temperatures can be considerably reduced by applying HWMA (half-warm mix asphalt) technology, in which foamed bitumen is used as a binder [13]. Foamed bitumen allows manufacturing bituminous mixtures at temperatures less than 100 °C. In this technology, aggregates do not have to be completely dry as the thin water film on their surface has a beneficial effect on the additional foaming process [14]. Energy used in the drying process is reduced substantially as the temperatures used are lower than those of HMA or WMA mixtures production. These lower temperatures may have a negative effect on the formation of the film on the aggregate surfaces. Also compaction at temperatures lower than 100 °C may lead to an excessive content of air voids. As a result, the layer may not obtain the required moisture resistance and be susceptible to damage. One of the methods applied to prevent these negative effects is to use foamed bitumen with high expansion ratio (*ER*) and half-life (*HL*) obtained as a result of pre-foaming bitumen modification with the use of low viscosity modifiers, for example, *FT* wax [15].

The issue of water susceptibility of bituminous mixtures is particularly important in moderate climate regions, including Poland. Water susceptibility accompanied by low temperatures in the winter season may cause a failure of the surface course in the pavement. Due to complexity of the process, laboratory evaluations of the mixture's resistance to these environmental factors are difficult and studies are being conducted to develop a procedure that will best simulate real field conditions. The indirect tensile strength ratio (*ITSR*) is the popular assessment criterion used to determine moisture resistance of mineral-bitumen mixes [16], however the methodology for water susceptibility evaluation has changed over the last years and, as shown in Table 1, it varies even throughought the EU and member states of the European Committee for Standardisation (CEN).

Poland, compared with other European countries, has the most severe requirements for water resistance indicated by the highest required *ITSR* values along with the use of wet conditioning with one freeze cycle. Besides Poland, freeze cycles are used in Turkey (AASHTO T283 [19]) and Finland (10 freeze–thaw cycles).

The experiences with HMA under moisture resistance tests is well documented and means to achieve adequate performance of mineral-bitumen mixtures are well understood and established. On the other hand, the emerging technologies of low temperature mixes, including HWMA with foamed bitumen require intensive investigations in this field.

While assessing the feasibility of any bitumen modification in HWMA technology, the economic calculation has to include all possible aspects of the production and service the final mix. The investigated asphalt mixes include an AC 8 HWMA wearing course mix based on a 50/70 bitumen, that is modified by the addition of 2.5% of Fischer-Tropsch wax (by bitumen mass). In this example, the increase in the cost of the mix constituents due to the incorporation of *FT* wax varies greatly depending on the constantly changing price of bitumen. However a rough calculation can be made. Taking into account the present (July, 2016) low oil and bitumen prices, the *FT* wax modification increases the cost of bituminous binder by ca. 31% and material costs of the whole mix by ca. 12% (any increase in bitumen prices will decrease this figure). On the other hand, the lowered HWMA processing temperatures can potentially lead to significant economic savings and ecological benefits, which are mostly related to the lower processing and paving temperatures. While it is claimed that the WMA technology, in most favourable conditions, permits the reduction in CO_2 emissions even by 40% and volatile organic compound emissions even by 50% [20], it is reasonable to say that the use of HWMA techniques will yield similar decrease in emissions easily. As the CO_2 is mostly produced in the process of heating the bitumen and aggregates up to the processing temperatures, the relative reduction in CO_2 emissions is directly proportional to the reduction in fuel consumption at the mixing plant and it relates to decreased asphalt production cost. Additionally, the *FT* wax modification allows the bitumen processing temperatures before foaming to be lowered by approx. 20 °C, as the decreased viscosity of *FT* modified bitumen allows the bitumen temperature to be decreased from 170 °C to 150 °C [15]. Taking into account the aforementioned benefits of the HMWA technology and possible positive effects of *FT* wax modification on the durability of the produced mixes, the material costs of introducing Fischer-Tropsch wax to HWMA mixes may eventually become insignificant.

This paper presents results of moisture resistance tests using two slightly different procedures with one freeze cycle. The tests were conducted on HWMA mixtures produced with foamed bitumen and on a control HMA mix. The investigations focused on the susceptibility of the HWMA mixture to the thermal shock during wet conditioning of Marshall samples, but the testing programme included also the analysis of compactibility and the evaluation of the effects of air void content on strength parameters.

2. Tested materials and methodology

2.1. Experimental program

The performance of the HWMA mixes was evaluated by testing the following parameters of Marshall compacted samples:

- air void content (V_m) to EN 12697-8:2005 [21], after 35, 50 and 75 blows per sample face,
- moisture resistance based on the evaluation of:
  - indirect tensile strength for a set of wet specimens ($ITS_{w(A)}$, $ITS_{w(B)}$) conditioned according to procedures specified in p. 2.3, as well as a set of dry specimens (ITS_d),
  - indirect tensile strength ratio ($ITSR_{(A)}$, $ITSR_{(B)}$).