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Influence of soiling phenomena on air-void microstructure and acoustic performance of porous asphalt pavement

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HIGHLIGHTS

- Artificial soiling tests were conducted to investigate the soiling mechanisms of porous asphalt.
- Changes of sound absorption behavior because of soiling are measured and modelled.
- Changes of flow resistivity, structure factor and tortuosity due to soiling are measured and modelled.
- Sound absorption parameters are determined for different mix designs and layer thicknesses.
- Different (sound) absorber models for porous asphalt are applied.

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ABSTRACT

Acoustical properties of porous asphalt and relationships with the structure of voids are analyzed. A special focus is put on the change of porous asphalt properties due to soiling, which is widely known as an essential problem of acoustical lifetime. Soiling mechanisms which are analyzed in artificially soiled samples with imaging techniques (thin sections and scanning electron microscopy) and their relevance to acoustical parameters are shown. Flow resistivities and sound absorption behaviour (frequencies and degree of sound absorption) are measured, structure factors and tortuosities are back-calculated with absorber models and compared according to mix design and changes due to soiling phenomena.

1. Introduction

Porous asphalt (as a general term for "European" mixes as well as open-graded friction courses) was developed in the 1930s [1] and has been widely used as wearing course since the 1980s [2–5]. Due to its comparatively high void content which is usually above 20% [6,7], porous asphalt (PA) has outstanding drainage and acoustical noise-reducing properties:

- Water can infiltrate into the PA layer and thus improve road traffic safety by reducing the danger of hydroplaning, spray and light reflections at night. Moreover, rain water can be retained within the porous structure for a certain period of time. This effect can relieve drainage constructions such as underground pipes or reservoirs during heavy rain events.
- PA has a high content of interconnected and accessible air void structure, which can work as a porous absorber in an acoustical sense. These sound-absorbing properties lead to a decrease of rolling noise and even engine noise. Furthermore, air-pumping mechanisms and other relevant aero-dynamical effects of the sound-generation of rolling tires can be reduced by the

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infiltration of air into the porous surface [8]. Surface texture and stiffness of pavements are further important influence factors of rolling noise which will not be discussed in this paper.

In contrast, however, the high void content and the granular structure which depends on the point-to-point bonding of aggregates lead to several mechanical deficiencies. In particular, its shorter lifetime concerning material deterioration due to ravelling [9–11] and the accelerated ageing effects of bitumen because of water and air infiltration and the higher potential of moisture damage (e.g. stripping) [12–15]. Thus, PA exhibits a shorter lifetime compared to conventional asphalt mixes because of the abovementioned material deteriorations.

Basically, it can be said that the void content as well as the structure of the pores (e.g. shape, interconnectivity and pore diameters) have crucial effects on both the mechanical and functional properties of PA [16]. The microstructural characteristics of air-void do not exhibit constant properties both spatially and temporarily. It is well-known that the soiling and clogging effect leads to a quantifiable and testable alteration of the porous structure [17–19]. In order to simulate the soiling process during the lifetime of PA, artificial soiling tests (AST) were developed in this study. The soiling mechanism is analyzed by the image analysis of thin sections with a light-optical microscope and by scanning electron microscopy images. The porous structure changes are investigated by means of acoustic properties (sound absorption) and parameters related to spatial and acoustic characteristics (flow resistivity, porosity) of the specimens with different soiling states – including the unsoiled state. The impact of relevant parameters concerning the pores' structure and acoustics such as structure factor and tortuosity, and their changes due to soiling mechanisms, are analyzed comprehensively by using acoustical absorber modelling as well as the results of measurements.

2. Methodology

2.1. Experimental program and analyses

For this study, porous asphalt mixes with different grain sizes/mix designs and layer thicknesses are considered. Table 1 shows the mix designs (according to [17]) and the resulting volumetric properties of the specimen. The binder is polymer-modified bitumen; granite is used as coarse aggregate and the filler consists of limestone.

In the Artificial Soiling Test (AST), PA samples with 2.5 m^2 (1.0 m × 2.5 m) were soiled in laboratory experiments by flushing a certain amount of (artificial) dirt into the porous structure by artificial rainfall in several steps, which is introduced in detail in Section 2.2.

Four soiling states were simulated:

- unsoiled/new
- soiled with 480 g/m^2
- soiled with 960 g/m^2
- soiled with 1440 g/m^2

The soiling states/amounts of dirt have been chosen in [17] according to the experiences of cleaning/sweeping procedures from porous and non-porous asphalt surfaces from different literature (e.g. [40,41]). Due to efficiency, not every soiling state has been applied to each specimen/type of mix design; so the PA 11 and twinlay PA 5/PA 11 mix designs have only been soiled with a medium soiling state of 960 g/m^2 while the others have been soiled with all of the soiling states. From the drill cores (diameter 10 cm) taken from the 2.5 m^2 porous asphalt samples, the different soiling states can be recognized at the surface (see Fig. 1). It should be mentioned that, of course, not only the surface but the whole porous structure is soiled by the AST described in Section 2.2. The following analyses and measurements have been conducted:

- Image analysis with thin sections and scanning electron microscopy has been done with specimens from unsoiled and soiled states.
- Before and after the AST, flow resistivity Ξ and sound absorption $\alpha(f)$ have been measured.
- Moreover, the change of properties which are important for the acoustical and sound-absorbing behaviour has been analyzed by determining further acoustical parameters such as structure factor κ or tortuosity τ.

Table 1
Volumetric properties of PA used in the study [17].

Mix type	PA 8	PA 11	Twinlay PA 8/PA 16		Twinlay PA 5/PA 11	
Layer thickness [cm]	4.0	4.0	Bottom layer, 4.5	Top layer, 2.5	Bottom layer, 4.5	Top layer, 2.5
Void content [Vol.-%]	25.3	27.2	27.7	25.3	27.7	25.1
Binder content PmB 45 A [M.-%]	6.3	6.3	6.1	6.3	6.3	6.6
	Mix design/gradation [M. % by mass of aggregates]					
0–0.09 mm	3.7	3.7	3.7	3.7	3.7	3.7
0.09–0.25 mm	0.3	0.3	0.3	0.3	0.3	0.3
0.25–2.0 mm						3.4
2.0–5.6 mm	4.5			4.5		87.9
5.6–8.0 mm	87.3	5.5		87.3	5.5	4.7
8.0–11.2 mm	4.2	87.4	4.1	4.2	87.4	
11.2–16.0 mm		3.1	87.6		3.1	
16.0–22.4 mm			4.3			

Fig. 1. Porous asphalt drill cores from different 2.5 m^2 porous asphalt samples (exemplary for PA 8 from left to right: soiled with 1440 g/m^2; soiled with 480 g/m^2; unsoiled/new).