Porous Road Surfaces: Acoustical Characteristics, Models and Measurements

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The paper introduces a research project which is aimed to give a basis for the optimization of porous road pavement. Within the project existing acoustical models for porous asphalt are examined as well as new ones which allow the prediction of acoustical properties from technological parameters rather than from classic parameters of porous absorbers. Some results of a thorough survey of the properties of a larger number of porous asphalt samples will be presented. Within the paper an overview about specially designed measurement equipment will be given too.

INTRODUCTION

One efficient way to attenuate road traffic noise is the use of porous asphalt layers. According to the results of latest publications this road surface can reduce the radiated sound power also by low traffic speed. Among others this effect arises due to the absorbing properties of the surface. For the optimization of the aforementioned absorbing layer a suitable theory for the determination of the acoustic properties, the characteristic impedance $\underline{Z}_A$ and the propagation constant, γ_A is required. In the literature proposals for the optimal value of the flow resistivity are given. However during the examinations it was found that there are more parameters with a significant influence, e.g. the porosity of the layer and the geometry of the pores (tortuosity).

THE ACOUSTIC PROPERTIES

A porous road surface is composed of a gravel mixture and bitumen. By use of a suitable gravel mixture consisting of different classes of grain size the occurrence of accessible cavities is achieved.

In the frequency range of interest the structure of the porous road surface shall be assumed as homogeneous. The acoustic behavior of a homogeneous absorber can be quitely described by employing the acoustic properties. There is a wide range of theories, which allow the calculation of the acoustic properties by use of the parameters of the absorber (e.g. porosity σ). Some of them consider in addition to the porosity σ and the flow resistivity Ξ also the geometry of the cavities, e.g. the so named phenomenological model. The latter theory seems to be feasible for calculation of the acoustical properties of the porous road surface. Here the geometry of the cavities is considered using the parameter tortuosity τ^2 (the square of the ratio of effective length of a flow path through a porous layer and the thickness of the layer).

THE MODEL OF THE ROAD STRUCTURE

The input parameters of the model, the porosity σ, the flow resistivity Ξ and the tortuosity τ^2 can be found by measurement. In the study a pool of approximately 150 specimen with different grain size and grain geometry was examined. But the optimization of the road surface requires the targeted change of the technological parameters (e.g. grain size). Therefore a model which enables the determination of the absorber parameter with the structure of the road as input was set up. This model bases on the theory of the sphere packing [1]. By that for the prediction of the flow resistivity the Equation (1) can be used.

Figure 1 shows the comparision between the measured value and the predicted value of the of the flow resistivity according to Eq. 1 (the porosity is obtained by measurement). A good agreement for most of the values determined is visible.

$$\Xi = \frac{\eta_A \left(1-\sigma+\sigma_p\right)^2}{2e^{-6}\left(\sigma-\sigma_p\right)^3 \cdot \bar{D}^2} \qquad (1)$$

(η_A dynamic viscosity of the fluid (air); $\bar{D}$ mean value of the diameter of the grains; σ_p percolation threshold)

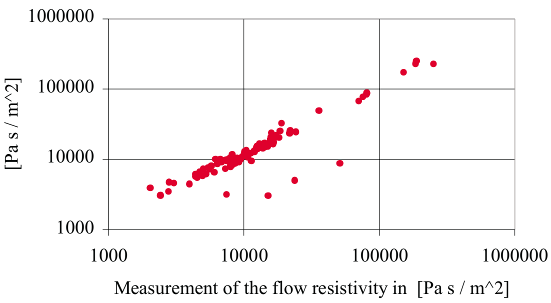

Figure 1. A comparison of the measured and the predicted (Eq. 1) flow resistivity.

THE DETERMINATION OF THE ABSORBING PROPERTIES BY USE OF THE AUTO-POWER-DENSITY SPECTRUM

The successful optimization of the porous road surface supposes the prediction of the sound field above the road. To proof this model an in-situ measurement technique had to be applied. One of the commonly used procedure is the so called 'impulse-echo-method'. This technique is often applied by executing the subtraction technique, a method of signal analysis. Here the absorbing properties are calculated from the results of two measurements each in different spatial orientation to the surface. The precision of the 'subtraction'-technique depends strongly on the agreement of the values of the group delay and the length of propagation path for both measurements. An deviation of temperature between the two measurements leads to inaccuracy in the results. Moreover the inaccuracy arises in the upper frequency range. Therefore an alternative technique of signal analysis was introduced:

The sound field of an point source above an surface (the size of the surface dimensions should be large compared to the wave length considered) is affected by the acoustical properties of the surface. In a certain distance to the source the sound pressure is:

$$\underline{p}(\omega) = \underline{Q}_d(\omega)\cdot e^{-j\omega t_d} + \underline{H}(\omega)\cdot \underline{Q}_r(\omega)\cdot e^{-j\omega t_r} \qquad (2)$$

By a known position of the measuring point this equation consists of two unknown values, the complex amplitude of the radiated sound $\underline{Q}(\omega)$ (considering the inverse-distance-law; $\underline{Q}_d$ path: source / measurement point; $\underline{Q}_r$ path: source / surface / measurement point) and the transfer function of the acoustical reacting surface $\underline{H}(\omega)$. That means for the calculation of $\underline{H}(\omega)$ a second equation is required. So one more measurement ($p_2(\omega)$) in another spatial orientation of measurement gear has to be carried out. The auto-power-density spectrum of Eq. 2 is:

$$\left|\underline{p}_1(\omega)\right|^2 = \left|\underline{Q}_{d1}(\omega)\right|^2 \left[1+\frac{\underline{Q}_{r1}(\omega)}{\underline{Q}_{d1}(\omega)}\underline{H}(\omega)\cdot e^{-j\omega(t_{r1}-t_{d1})}\right] \qquad (3)$$

$$\cdot\left[1+\frac{\underline{Q}_{r1}(\omega)}{\underline{Q}_{d1}(\omega)}\underline{H}^{\otimes}(\omega)\cdot e^{+j\omega(t_{r1}-t_{d1})}\right] \qquad \otimes\, conj.\ complex$$

Now $\underline{H}(\omega)$ is found by windowing the second term of Eq. 3 in 'time domain' and considering the sound pressure $p_2(\omega)$ as well as the inverse-distance-law for the path length r.

$$\underline{H}(\omega) = \frac{\left|\underline{Q}_{d1}(\omega) r_{d,1}\right|^2}{\left|\underline{p}_2(\omega) r_{d,2}\right|^2}\,\frac{\underline{Q}_{r1}(\omega)}{\underline{Q}_{d1}(\omega)}\,\underline{H}(\omega)\cdot e^{-j\omega(t_{r1}-t_{d1})}\cdot\frac{r_{r1}}{r_{d1}}\,e^{j\omega\left(\frac{r_{r1}-r_{d1}}{c_1}\right)} \qquad (4)$$

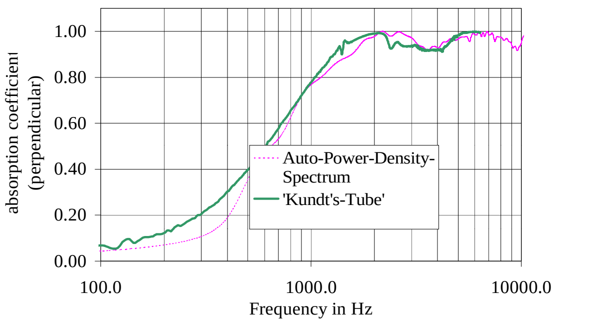

Figure 2. A comparison to determine the absorption coefficient perpendicular of an open-cell foam.

Figure 2 shows the absorption coefficient for perpendicular incidence. Notice the good agreement especially in the upper frequency range.

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