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Improvements to the Johnson–Allard model for rigid-framed fibrous materials

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Abstract

Measurements of the surface impedance and the physical parameters of seven glass wool samples and six polyester fibre samples with flow resistivities between 4100 and 69,900 Pa s m^{-2} have been made. Comparisons of measured absorption coefficients and those predicted from the Johnson–Allard formulae using the measured and deduced physical parameters show discrepancies that exceed 20% for some samples and frequencies. By modifying the Johnson–Allard formula for effective density and by introducing a correction factor that is a function of flow resistivity based on data fitting, it has been found possible to improve the predictions. However, it has also been found that a similar modification of the formula for bulk modulus is necessary to reduce the discrepancies with data to below 5% in the frequency range between 800 Hz and 5 kHz.

Keywords: Flow resistivity; Tortuosity; Viscous characteristic length, Thermal characteristic length

1. Introduction

Adequate models for predicting the acoustical properties of fibrous materials are important in the building acoustics. Although based on many measurements, the semi-empirical single-parameter (flow resistivity) model of Delany and Bazley [1] has been

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found to have some shortcomings [2]. A more comprehensive semi-empirical model, the Johnson–Allard model [3–7], requires five parameters introducing porosity, tortuosity and two characteristic lengths in addition to flow resistivity. In Section 2, careful measurements of the acoustical and physical properties of glass wool and polyester fibre materials are described. Using the measured and calculated parameter values, it is shown that the Johnson–Allard model does not perform noticeably better than the single-parameter Delany and Bazley model and that both give rise to substantial discrepancies between predictions and data for normal incidence absorption coefficient. Subsequently, in Section 3, the Johnson–Allard expressions for effective density and bulk modulus are re-expressed and modified empirically through two correction factors based on data fitting. In Section 4, it is shown that the new form of the Johnson–Allard model gives significant improvements in the agreement between predictions and data. Finally, Section 5 presents concluding remarks.

2. Measurements and model comparisons

2.1. Material

Table 1 details the seven glass wool samples and Table 2 the six polyester fibre samples used in the experiment.

2.2. Performance of the Johnson–Allard model

The measured four physical parameters and the calculated porosity were substituted for the Johnson–Allard model. The prediction error of the normal incidence absorption

Table 1
Measurements of the glass wool samples, except porosity, obtained by calculation

Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
ρ_1 (kg m^{-3})	28.0	31.8	41.7	52.6	81.2	101.2	84.7
b (mm)	25.0	25.0	24.5	25.0	10.0	14.0	14.0
σ (Pa s m^{-2})	11,900	16,800	21,500	29,000	49,000	69,900	53,300
α_∞	1.0108	1.0093	1.0124	1.0144	1.0295	1.0358	1.0304
$\wedge$ (μm)	143	132	106	87	57	48	52
$\wedge'$ (μm)	302	237	225	184	123	97	126
ϕ	0.989	0.987	0.983	0.979	0.968	0.960	0.966

Table 2
Measurements of the polyester fibre samples, except porosity, obtained by calculation

Sample	Sample 10	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
ρ_1 (kg m^{-3})	35.9	72.9	49.8	72.8	49.9	64.4
b (mm)	14.0	12.5	10.5	10.5	12.0	11.0
σ (Pa s m^{-2})	19,700	51,000	9800	17,400	4100	5700
α_∞	1.0206	1.0471	1.0328	1.0494	1.0354	1.0464
$\wedge$ (μm)	125	67	152	113	269	206
$\wedge'$ (μm)	221	128	292	218	541	399
ϕ	0.974	0.947	0.964	0.947	0.964	0.953