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A simple empirical model of polyester fibre materials for acoustical applications

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Abstract

A new empirical model has been developed by the authors to predict the flow resistivity, acoustic impedance and sound absorption coefficient of polyester fibre materials. The parameters of the model have been adjusted to best fit the values of airflow resistivity and sound absorption coefficient measured over a set of 38 samples. Calculated results are compared with normal incidence measurements carried out using two different techniques: the transfer-function method in an impedance tube (ISO 10534-2) and the free-field impulse response method (ISO 13472-1). Measurements performed on polyester fibre materials with different density and thickness values, and diameter ranging from 18 to 48 μm, are in good agreement with the predictions of the new model. It is concluded that the new model can predict the basic acoustic properties of common polyester fibre materials with any practical combination of thickness and density[2].

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Keywords: Polyester fibre materials; Airflow resistivity; Acoustic impedance; Sound absorption coefficient

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1. Introduction

Polyester fibre materials are an innovative class of products, quickly becoming of widespread use as sound absorbers; in particular, they are more and more used to replace glass wool and rock wool where it is required to keep the environment free of fibres suspected to have an influence on human health. On the other hand, scientific literature is lacking of studies on the physical and acoustical characteristics of polyester fibre materials; no specific model for predicting the sound absorption coefficient exists. Narang [1], in one of the few works devoted to the acoustical behaviour of such materials, put in evidence that the well known models developed for glass wool and rock wool are not well suited for polyester fibres and invited to develop new correlations for this kind of materials. To the authors' knowledge, no other studies exist published at international level and specifically devoted to polyester fibre materials. Therefore, the main goal of the present work is the development of a new simple model of flow resistivity, acoustic impedance and sound absorption coefficient of polyester fibre materials and the experimental verification of its reliability for engineering applications. The effects of the variation of some typical characteristics of this kind of material, such as the percentage of "bicomponent" fibres and the presence of a smoothed surface layer obtained by a thermal treatment, were also investigated.

2. Review of previous wok

2.1. Airflow resistivity models

Few works can be found in the scientific literature devoted to the prediction of the airflow resistivity of fibrous materials from their basic properties. Bies and Hansen [2] presented a simple model which allows the calculation of the airflow resistivity of a fibrous material starting from the values of its bulk density and fibre diameter. Inspection of the data presented in their work, Fig. 6 in particular, suggests that the model is valid if the material has a fairly uniform fibre diameter, in the range from 1 to 15 μm, and if any binder does not play too large a part. The same model is recalled also in one of the most popular textbooks on noise control [3], together with a similar expression proposed earlier by Nichols [4]. Narang [1] investigated specifically polyester fibre materials, having a fibre diameter ranging from 12 to 26 μm. He concluded that the airflow resistivity of such materials does not seem to follow the empirical relations developed for fibre glass and proposed a regression equation relating the airflow resistivity to the number of polyester fibres per unit volume. Given the correct values of airflow resistivity, he estimated the sound absorption coefficient using an empirical model developed for fibre glass, although for greater precision he recommended to determine new regression coefficients valid for polyester fibres.

2.2. Acoustical models

Many works can be found in the scientific literature devoted to the prediction of the characteristic acoustic impedance and propagation constant of fibrous materials from their basic properties. Hence, under a plane wave propagation hypothesis, the sound absorption coefficient can readily be obtained. These models can be classified as empirical, phenomenological or microstructural.

Probably the best-known empirical model is that of Delany and Bazley [5], who presented simple power-law relations obtained by best-fitting a large amount of experimental data. Their model needs just one input parameter, the airflow resistivity, easily measurable. This can explain the success of this model. They also provided a graph for estimating the airflow resistivity of a fibrous material from its bulk density. Dunn and Davern [6] retained the same equation forms and calculated new regression constants for polyurethane foams, using few samples having low airflow resistivity values. Wu [7] extended the preceding work using more samples of porous plastic open-cell foam, thus covering a wider airflow resistivity range. Voronina [8,9] used comparative analysis of experimental results (for materials having a fibre diameter from 1 to 10 μm) to derive the characteristic impedance and propagation constant as functions of the fibre diameter and porosity. An approximate expression for the airflow resistivity is also given [8]. Gardner et al. [10] used neural networks to implement an empirical model for polyurethane foams with one input parameter: the airflow resistivity. The algorithm embedded in the neural network substitutes the usual power-law relations.

Porous materials can also be studied using theoretical models. The so called phenomenological approach consists in replacing a fluid-saturated porous solid with an equivalent dissipative fluid. It was adopted, among others, by Morse and Ingård [11] for a rigid-frame porous material. Hamet [12] proposed an extended phenomenological model, taking into account both viscous and thermal dissipation. This model requires three parameters to characterise the material and is particularly well-suited for materials having a moderate porosity, like porous road pavements. A fundamental advancement was obtained by Biot [13], who developed a general theory of propagation of elastic waves in a fluid-saturated porous solid with an elastic frame. Lambert [14], using Biot's results, developed an analytical model for highly porous polyurethane foams and verified it with measurements of some structural parameters. A common weakness of these phenomenological models is that some parameters, e.g., the structure factor, cannot be calculated inside the model and need to be determined by fitting to measured acoustical data.

An approach of more fundamental nature, called the microstructural approach, consists in deriving the wave propagation inside individual pores from first principles and then generalising the results to the macroscopic scale. Zwikker and Kosten [15] applied this procedure to unconnected circular tubes. Attenborough [16,17] derived rigid-frame models for more complicated pore microstructures and showed that they can be applied both to fibrous and granular materials. These models require five free parameters, including the dynamic and static shape factors;

the number of parameters can be reduced to four making use of the "pore shape factor ratio", which is frequency dependent. Allard et al. [18] reviewed the Biot's theory, focusing on the case where air is the saturating fluid. They described a model using the dynamic density function given by Biot [13], the Zwikker and Kosten [15] expression for the dynamic bulk modulus and a frequency-independent shape factor. A detailed review of the work by Allard and colleagues can be found in a textbook by Allard [19]. Champoux and Stinson [20] proposed another five parameters model, including two different shape factors accounting for viscous and thermal effects, and verified it on model porous materials having an exactly known geometry. Wilson [21] developed a general three parameter model by matching relaxational characteristics of viscous and thermal properties and compared it to previous models. In general, the microstructural models provide a deep physical insight of sound energy dissipation mechanisms, but are inherently more complex and contain some parameters to be determined from a detailed knowledge of the material microstructure.

The aim of the present work is to define a model of polyester fibre materials in order to effectively support engineering design in noise control; the model should require in input easily measurable data and be as simple as possible. Therefore, the choice was for an empirical model where the key parameter is the airflow resistivity of the material, a quantity which can be measured using a standardised procedure [22].

3. The polyester fibre samples

The polyester fibre material investigated in the present work is manufactured in blankets with different density, thickness, composition and surface treatment. It is constituted by a mix of two different kind of fibres, in a percentage depending on the type of product (identified by the suffix "T" or "TE" in its name):

- fibres of polyethilenterephtalate, ranging from 70% to 80%;
- "bicomponent" fibres constituted by a core of polyethilenterephtalate and a lining of copolyester, ranging from 30% to 20%.

The lining of copolyester has its melting point at about 110 °C, while the polyethilenterephtalate has its melting point at about 255 °C. The mix of fibres is thermally treated at 150 °C in order to melt the external lining of the "bicomponent" fibres and form a skeleton of thermally bound fibres. The material is also pressed in order to obtain blankets of different thickness and density.

The circular section of the fibres has a diameter ranging from 18 to 48 μm; the mean fibre length is about 55 mm. These values are considerably greater than for glass wool fibres, usually having diameter values ranging between 1 and 10 μm; this is one of the physical factors causing a different acoustical behaviour of the two kinds of material. The fibres are mainly organised in bi-dimensional layers parallel to the two main surfaces of the blanket.

The blankets may be submitted to a thermal treatment of the two larger external surfaces by rolling them at 150 °C in order to get smooth surfaces. In this case the products are identified by the additional suffix "2SL" in their name.

For the present work, 38 polyester fibre samples has been used, different for density (ranging from 10 to 120 kg/m^3) and thickness (ranging from 10 to 120 mm) and belonging to the four types T, T2SL, TE, TE2SL. The samples were studied both globally and separately for each type. Table 1 reports the basic characteristics of

Table 1
Values of thickness, bulk density and airflow resistivity for the 38 samples of polyester fibre material

Name (type)	Nominal thickness (mm)	Mounting thickness (mm)	Bulk density (kg/m^3)	Airflow resistivity (Pa s/m^2)
Fiberform 62 T	50	91	20	1877
Fiberform 62 T	20	65	25	2110
Fiberform 62 T	20	55	30	2986
Fiberform 62 T	15	45	33	3578
Fiberform 62 T	20	39	35	3894
Fiberform 62 T	50	50	36	3682
Fiberform 62 T	50	48	38	3931
Fiberform 62 T	10	30	50	5119
Fiberform 62 T 2SL	25	123	12	922
Fiberform 62 T 2SL	35	103	14	1110
Fiberform 62 T 2SL	30	82	17	1465
Fiberform 62 T 2SL	40	77	18	1700
Fiberform 62 T 2SL	40	75	20	2059
Fiberform 62 T 2SL	39	75	26	2628
Fiberform 62 T 2SL	30	59	27	2722
Fiberform 62 T 2SL	50	48	30	2958
Fiberform 62 T 2SL	18	51	33	3734
Fiberform 62 T 2SL	40	39	35	3937
Fiberform 62 T 2SL	40	39	38	4390
Fiberform 62 T 2SL	25	50	40	4972
Fiberform 62 T 2SL	20	40	40	5093
Fiberform 62 T 2SL	40	39	40	5112
Fiberform 62 T 2SL	15	30	60	8596
Fiberform 62 T 2SL	10	18	110	22,699
Fiberform 62 TE	30	112	13	912
Fiberform 62 TE	42	130	14	880
Fiberform 62 TE	40	76	15	1101
Fiberform 62 TE	30	89	20	1363
Fiberform 62 TE	22	67	25	1839
Fiberform 62 TE	30	56	27	2885
Fiberform 62 TE	70	69	30	2523
Fiberform 62 TE 2SL	68	135	15	1192
Fiberform 62 TE 2SL	30	100	15	1423
Fiberform 62 TE 2SL	60	58	23	2111
Fiberform 62 TE 2SL	50	95	24	2772
Fiberform 62 TE 2SL	20	59	25	2520
Fiberform 62 TE 2SL	10	50	30	2630
Fiberform 62 TE 2SL	32	32	44	5356

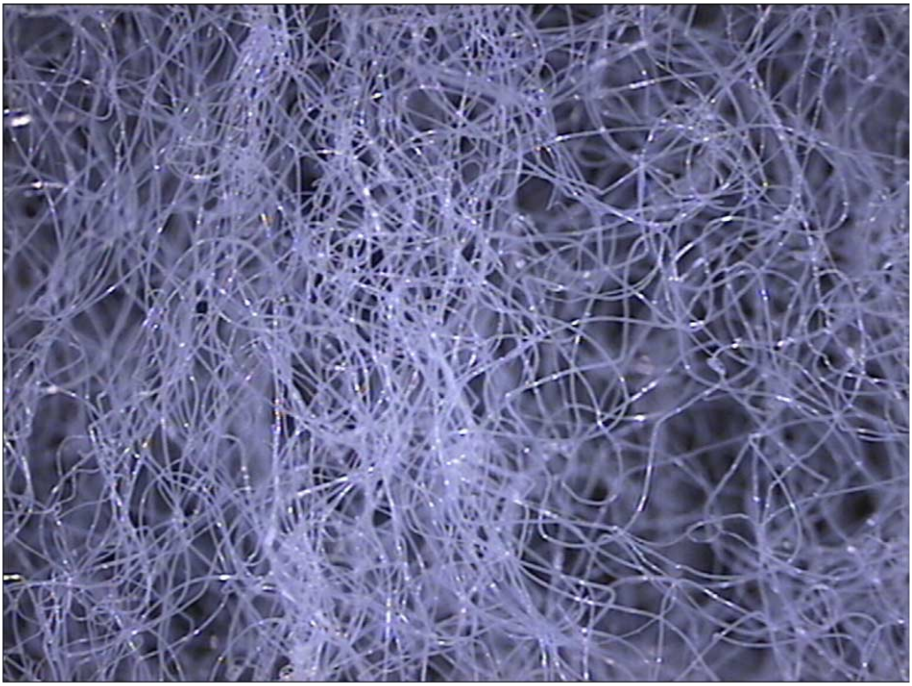

Fig. 1. Picture of a sample of polyester fibre material used in the present work (magnification 10×).

the samples. A picture (taken by a microscope with a magnification of 10×) of a sample of polyester fibre material used in the present work is shown in Fig. 1.

4. Measurements

The values of thickness and bulk density were declared by the manufacturer and checked again in the laboratory. In Table 1, the values of the "nominal" thickness are those declared by the manufacturer, the values of the "mounting" thickness are those verified on the sample when mounted in the measurement device for the determination of the airflow resistivity (see below). When the mounting thickness is two or three times larger than the nominal thickness, it is because the sample was arranged in two or three layers into the measuring device in order to have a reading of the airflow resistance well inside the valid measurement range of the device.

The airflow resistivity was measured using the alternate airflow method described in the EN 29053 standard [22]. The measuring device was previously tested and found very reliable during a European inter-laboratory test [23]. The measured values of airflow resistivity are reported in Table 1.

The sound absorption coefficient was measured using the well known transfer-function method in an impedance tube described in the ISO 10534-2 standard [24].

5. A new model for airflow resistivity – NMR

Bies and Hansen presented a simple model [2] which allows the calculation of airflow resistivity values starting from the values of the bulk density of the fibrous material and the fibre diameter:

$$rd^2\rho_{\mathrm{m}}^{-K_1} = K_2, \tag{1}$$

where r is the airflow resistivity (Pa s/m^2), ρ_{m} is the bulk density (kg/m^3) and d is the mean fibre diameter (m). $K_1 = 1.53$ and $K_2 = 3.18 \times 10^{-9}$ for fibre glass. Bies and Hansen claim that the quadratic dependence on the fibre diameter has been verified experimentally. The above empirical equation assumes uniform fibre diameter (<15 μm) and negligible binder content.

Unfortunately, the straightforward application of the Bies and Hansen model to polyester fibre materials gives a large underestimation of airflow resistivity values in comparison to measured ones (see Fig. 2). Probably, this is due to the fact that polyester fibres have larger diameter values, and more dispersed; according to the manufacturer's declaration, for the samples used in the present work they range from 18 to 48 μm; the mean fibre length is 55 mm. Thus, it was decided to use the model with a single value of the diameter, its mean value $\langle d\rangle = 33$ μm, that is significantly larger

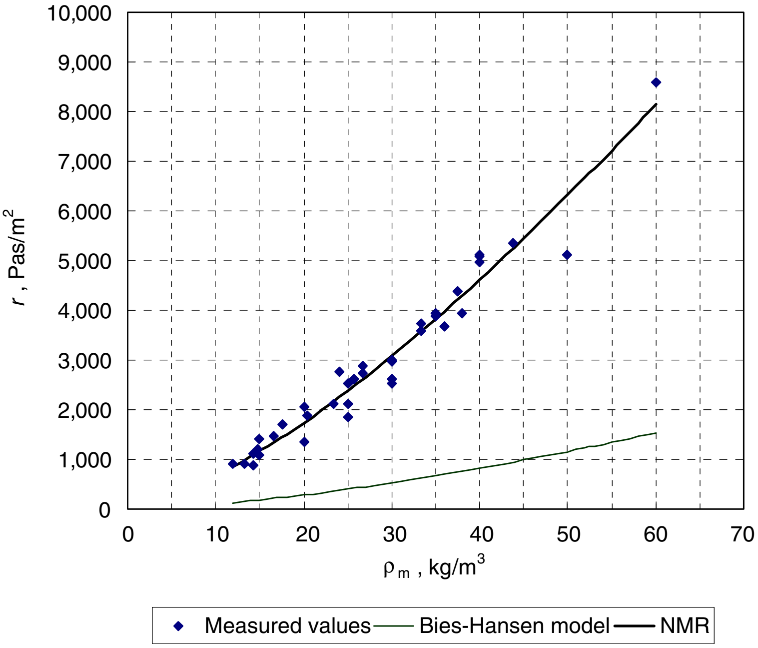

Fig. 2. Airflow resistivity as a function of the bulk density: comparison between measured and predicted values for polyester fibre materials. Squares: measured values; thin curve: Bies–Hansen model [2] with $\langle d\rangle = 33$ μm; thick curve: NMR model developed in the present work.

Table 2
Values of the parameters A and B in Eq. (1) from the Bies–Hansen formulation [2] with a mean fibre diameter of 33 μm and from the best-fit described in the present work for polyester fibre materials (NMR)

Model	A	B
Bies–Hansen	2.920	1.53
NMR	25.989	1.404

than those on which the Bies–Hansen model was fitted. With this choice Eq. (1) can be modified as:

$$r = A\rho_{\mathrm{m}}^{B}, \tag{2}$$

where $A = K_2\langle d\rangle^{-2}$ and $B = K_1$. A and B are free parameters. The idea of relating simply the airflow resistivity and the bulk density for rapid noise control purposes is not new in the existing technical literature and can be traced back to the original work of Delany and Bazley (see Fig. 10 of [5]).

It was decided to find the optimal values of A and B for polyester fibres by least-squares best-fitting the values of airflow resistivity calculated with Eq. (2) on the measured data. The results are: $A = 25.989$ and $B = 1.404$. Table 2 compares the values of the parameters A and B in Eq. (1) from the Bies–Hansen formulation [2] with a mean fibre diameter of 33 μm and from the best-fit described in the present work for polyester fibre materials.

The sample having density 110 kg/m^3 was not considered in the best-fit procedure, because it was found non-homogeneous to the others, which have density values ranging from 12 to 60 kg/m^3.

Eq. (2) with the best-fit values of A and B constitutes a simple model for polyester fibre materials and has been called the new resistivity model (NMR). As can be seen in Fig. 2, the NMR model can predict with a quite good accuracy the airflow resistivity of polyester fibre materials as a function of their bulk density. The mean deviation of calculated values from measured ones is 9.8%. A more detailed analysis separating the four different types of material did not reveal a measurable influence of the binder fibre percentage or the surface smoothing treatment; therefore it was decided to keep the global values of A and B given above and to not use a separate empirical relation for each kind of polyester fibre material.

6. A new model for impedance

The predictive model for the normal-incidence sound absorption coefficient has been derived from the well known Delany–Bazley [5] power-law relations:

$$Z_{\mathrm{R}} = \rho_0 c_0\left[1 + C_1\left(\frac{\rho_0 f}{r}\right)^{-C_2}\right], \tag{3}$$

$$Z_{\mathrm{I}} = -\rho_0 c_0 \left[C_3 \left(\frac{\rho_0 f}{r} \right)^{-C_4} \right], \tag{4}$$

$$\alpha = \left(\frac{2\pi f}{c_0} \right) \left[C_5 \left(\frac{\rho_0 f}{r} \right)^{-C_6} \right], \tag{5}$$

$$\beta = \left(\frac{2\pi f}{c_0} \right) \left[1 + C_7 \left(\frac{\rho_0 f}{r} \right)^{-C_8} \right], \tag{6}$$

where Z_{R} and Z_{I} are the real and imaginary parts of the characteristic acoustic impedance Z, α and β the real and imaginary parts of the propagation constant γ, ρ_0 is the air density and f is the frequency.

From this equations, the sound absorption coefficient at normal incidence, α_{n}, for a rigidly backed fibrous layer of thickness l can be obtained using the well known formulae:

$$Z_l = (Z_{\mathrm{R}} + \mathrm{i}Z_{\mathrm{I}})[\coth(\alpha + \mathrm{i}\beta)l] = Z_{l\mathrm{R}} + \mathrm{i}Z_{l\mathrm{I}}, \tag{7}$$

$$\alpha_{\mathrm{n}} = \frac{4Z_{l\mathrm{R}}\rho_0 c_0}{|Z_l|^2 + 2\rho_0 c_0 Z_{l\mathrm{R}} + (\rho_0 c_0)^2}. \tag{8}$$

A specific model of this kind for polyester fibre materials cannot be found in the literature. It has been defined in the present work, allowing the eight coefficients $C_1, \ldots, C_8$ in Eqs. (3)–(6) vary and finding their optimal values by least-squares best-fitting the values of the sound absorption coefficient, calculated from the Eqs. (7) and (8), on the values measured in the impedance tube. This is a somewhat simplified procedure compared to what can be found in most of the previous literature, where usually the best fit is based on the values of both characteristic impedance and propagation constant [5,6], but has proven to work and give useful results for noise control purposes, as shown in Figs. 3–7. In an analogous way, Gardner et al. [10] trained their neural network on measured values of the sound absorption coefficient α_{n} and surface impedance Z_l (not characteristic impedance). Thus, in the present case the resulting model is optimised on the sound absorption coefficient of the above mentioned polyester fibre samples: Eqs. (3)–(8) with the best-fit values of $C_1, \ldots, C_8$ constitute a simple model for polyester fibre materials. It has been called the new impedance model (NMI).

As previously done for the NMR model, a more detailed analysis separating the various kinds of material has been conducted, but it did not reveal a measurable influence of the binder fibre percentage or the surface smoothing treatment.

Table 3 shows the values of the eight coefficients of the new NMI model for polyester fibre materials compared with the values found by Delany–Bazley [5] and Dunn–Davern [6]. Fig. 3 shows for the same sample the comparison between the measured values of the sound absorption coefficient at normal incidence and the values calculated using the Delany–Bazley [5] model, the Dunn–Davern [6] model and the NMI model. All models are used with the measured value of the airflow resistiv-

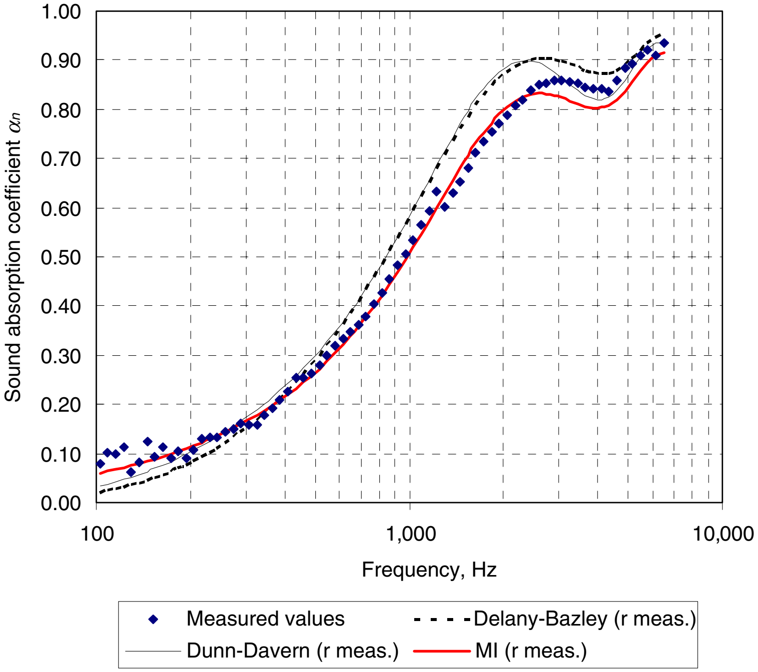

Fig. 3. Polyester fibre blanket type T2SL, with bulk density 40 kg/m^3 and thickness 40 mm. Sound absorption coefficient at normal incidence. Squares: measured values (impedance tube method); dashed curve: predicted values from the Delany–Bazley model [5]); continuous thin curve: predicted values from the Dunn–Davern model [6]); continuous thick curve: predicted values from the MI model (present work). All models used with the measured value of the airflow resistivity (5093 Pa s/m^2).

ity. As can be seen, the NMI gives better predictions both at low and high frequency. Table 4 shows the mean deviation between the measured values of the sound absorption coefficient and the calculated values using the NMI, the Delany–Bazley [5] and the Dunn–Davern [6] models for the sample of Fig. 3. On average, all models have an acceptable performance, but the NMI improves the accuracy by 34% in comparison to the Delany–Bazley model and by 20% in comparison to the Dunn–Davern model. Fig. 4 shows the same comparison for another sample of reduced density and thickness and without the thermal treatment on the main surfaces.

7. The integrated model

The integrated model MI is the final result of the study conducted on the polyester fibre materials. As seen above, the NMR model can predict the airflow resistivity as a function of the bulk density – Eq. (2) – and the NMI model can give the specific acoustic impedance and the propagation constant as a function of the airflow resistivity – Eqs. (3)–(6). Hence, the sound absorption coefficient at normal incidence can be easily obtained using the Eqs. 7,8.

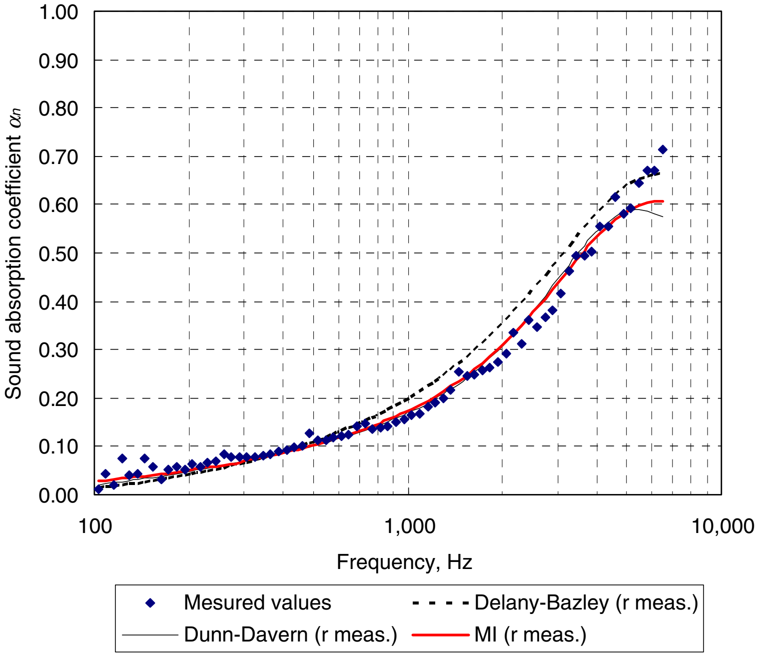

Fig. 4. Polyester fibre blanket type T, with bulk density 30 kg/m^3 and thickness 20 mm. Sound absorption coefficient at normal incidence. Squares: measured values (impedance tube method); dashed curve: predicted values from the Delany–Bazley model [5]); continuous thin curve: predicted values from the Dunn–Davern model [6]); continuous thick curve: predicted values from the MI model (present work). All models used with the measured value of the airflow resistivity (2986 Pa s/m^2).

The whole set of Eqs. (2)–(8), called the integrated model (MI), can therefore describe the acoustical characteristics of the material knowing only its bulk density and thickness. It is very useful because polyester fibre blankets are manufactured with many combinations of density and thickness and measured values of the sound absorption coefficient or the airflow resistivity are generally not (yet) available.

Figs. 5 and 6 show the large difference between the sound absorption coefficient values of the same samples of Figs. 3 and 4 calculated using the MI model and the Delany–Bazley [5] or the Dunn–Davern [6] model, starting from the values of thickness and bulk density. The Delany–Bazley and the Dunn–Davern models must rely on the airflow resistivity values calculated with the Bies–Hansen model, which gives a strong underestimation of the airflow resistivity, being developed for other kind of absorbers and not for polyester fibre materials. Hence an evident underestimation of the sound absorption coefficient. The integrated model MI gives a better prediction; for example, in the case of the sample of Fig. 3, with bulk density 40 kg/m^3 and thickness 40 mm, the curve of the sound absorption coefficient at normal incidence α_n is predicted with a mean deviation of 3% from the measured values.

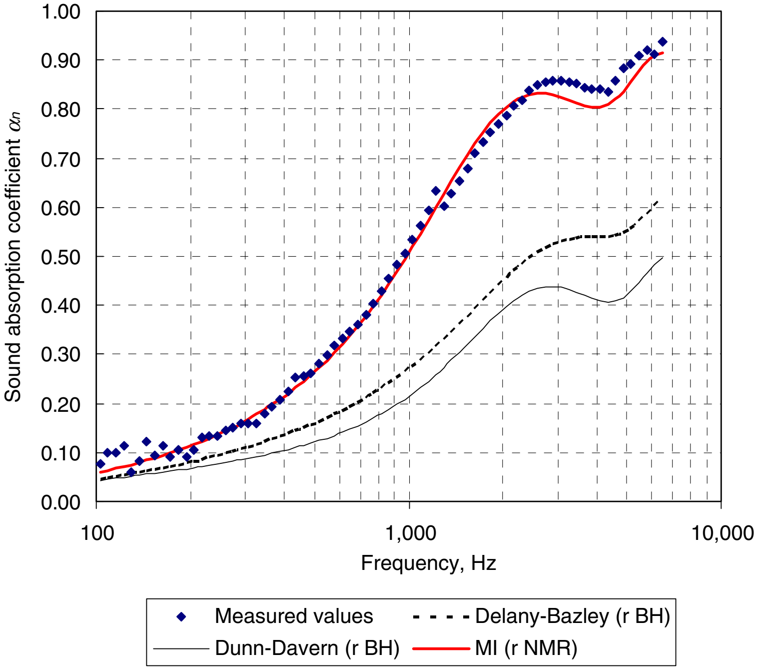

Fig. 5. Polyester fibre blanket type T2SL, with bulk density 40 kg/m^3 and thickness 40 mm. Sound absorption coefficient at normal incidence. Squares: measured values (impedance tube method); dashed curve: predicted values from the Delany–Bazley model [5]), using the airflow resistivity values calculated with the Bies–Hansen model [2]; continuous thin curve: predicted values from the Dunn–Davern model [6]), using the airflow resistivity values calculated with the Bies–Hansen model [2]; continuous thick curve: predicted values from the MI model (present work), using the airflow resistivity values calculated with the NMR model (present work).

8. Further experimental validation

In order to have an independent verification of the new empirical model MI, additional measurements have been done on polyester fibre materials not included in the original set of samples used for the development of the new model. The samples had an bulk density of 30, 40 and 60 kg/m^3 and a thickness ranging from 40 to 50 mm.

Measurements have been done using two different techniques: the transfer-function impedance tube method [24] already used for the first set of measurements (see above) and the free-field impulse method [25]. Fig. 7 shows the comparison of the sound absorption coefficient at normal incidence α_n for the 60 kg/m^3, 50 mm sample: above 140 Hz a good correlation is found between the values measured with the impedance tube method and those calculated using the integrated model MI; above 250 Hz a good correlation is found also with the free-field impulse method. It should also be remarked that the free-field impulse measurements were performed conforming strictly to the ISO 13472-1 specifications: this implies that valid measurements can be obtained in the one-third octave bands from 250 to 4 kHz. Further

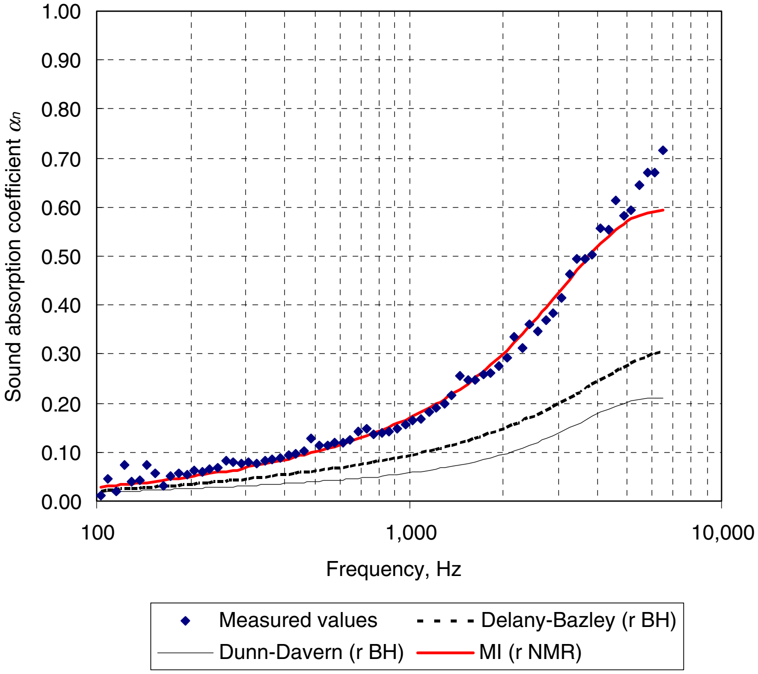

Fig. 6. Polyester fibre blanket type T, with bulk density 30 kg/m^3 and thickness 20 mm. Sound absorption coefficient at normal incidence. Squares: measured values (impedance tube method); dashed curve: predicted values from the Delany–Bazley model [5]), using the airflow resistivity values calculated with the Bies–Hansen model [2]; continuous thin curve: predicted values from the Dunn–Davern model [6]), using the airflow resistivity values calculated with the Bies–Hansen model [2]; continuous thick curve: predicted values from the MI model (present work), using the airflow resistivity values calculated with the NMR model (present work).

measurements are on going with different arrangements, allowing to get valid measurements in a broader frequency range.

9. Conclusions and future work

A new empirical model has been developed for predicting the airflow resistivity, acoustic impedance and sound absorption coefficient of polyester fibre materials. The whole set of equations, called the integrated model MI, can describe the acoustical characteristics of polyester blankets knowing only their bulk density and thickness.

The model has been developed by best-fitting the calculated values on the measured values of the relevant physical parameters for a set of 38 samples having a fibre diameter ranging from 18 to 48 μm. A further validation was performed, using not only the transfer-function method in an impedance tube (ISO 10534-2) but also the free-field impulse response method (ISO 13472-1).

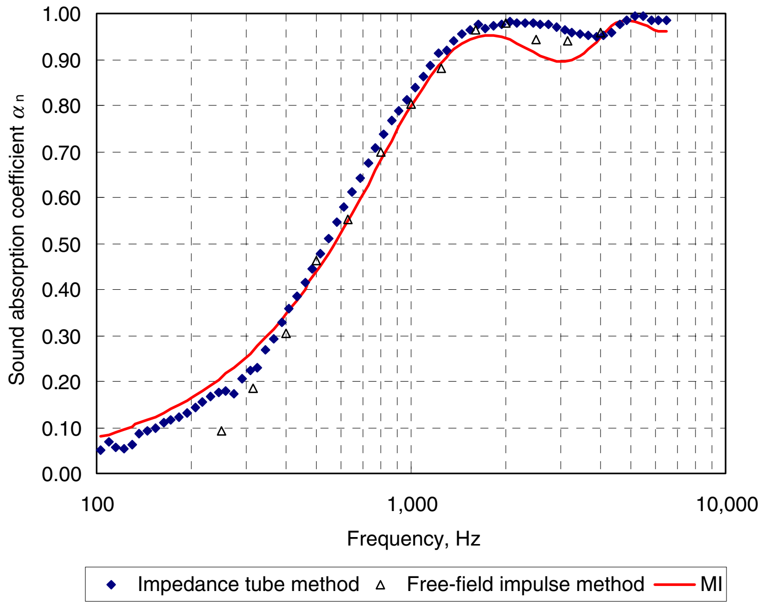

Fig. 7. Polyester fibre blanket type T, with bulk density 60 kg/m^3 and thickness 50 mm. Sound absorption coefficient values at normal incidence. Squares: measured values (impedance tube method); triangles: free-field impulse response method; continuous curve: calculated values using the MI model.

Table 3

Values of the eight coefficients in Eqs. (3)–(6) from the best-fit described in the present work for polyester fibre materials (NMI) compared with the values found by Delany–Bazley [5] and Dunn–Davern [6]

Model	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Delany–Bazley	0.057	0.754	0.087	0.732	0.189	0.595	0.098	0.700
Dunn–Davern	0.114	0.369	0.099	0.758	0.168	0.715	0.136	0.491
NMI	0.078	0.623	0.074	0.660	0.159	0.571	0.121	0.530

Table 4

Mean deviation between the measured values of the sound absorption coefficient at normal incidence and the calculated values using the NMI (present work), the Delany–Bazley [5] and the Dunn–Davern [6] models

Model	Mean deviation between calculated and measured α_n values (%)
Delany–Bazley	4.7
Dunn–Davern	3.9
NMI	3.1
MI	3.0

The sample is the same of Fig. 3 (polyester fibre blanket type T2SL, with bulk density 40 kg/m^3 and thickness 40 mm).

The new model has a better performance than older models developed for classical fibrous materials like glass wool.

The MI model is a simple tool that can be used by manufacturers and noise control engineers when detailed information on the material microstructure is not available.

Further work has already been planned to investigate the dependence of the flow resistivity on the fibre diameter, possibly taking into account its actual distribution, when enough data are available, and not only the mean value.

Moreover, measurements according to the free-field impulse response method (ISO 13472-1) are on going with different arrangements, allowing to get valid measurements in a broader frequency range, particularly at low frequency.

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