inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 35

INFLUENCE OF THE PORE SIZE DISTRIBUTION ON SOUND ABSORPTION OF RUBBER GRANULATES

P Allemon & R Hazebrouck

L A M H, Université d'Artois, 1230 rue de l'Université, BP 819 62408 Bethune cedex, France

1. INTRODUCTION

In air acoustics, manufactured porous materials are commonly used for their absorption properties. Here, our purpose is to study if these materials can be replaced by recycled granulates as sound absorbers in acoustic panel design. For that, a pulverulent recycled material made of crushed rubber granulates issued from worn out tires, has been used. This one is combined with a perforated metal facing. In a first step, the panel structure is presented. In a second step, the effect of grain size distribution on sound absorption properties of crushed rubber will be studied experimentally and theoretically.

2. PANEL STRUCTURE

From back to front of the panel, we have an impervious rigid wall, a 7 cm thick sound absorptive layer (crushed rubber), a thin sheet of glass wool presenting a very low air flow resistivity and a perforated metal facing. The facing plate has the following parameters : a thickness of 1 mm, a perforation diameter of 3 mm and a percent open area of 23 %. For that value, the perforated facing is almost transparent and the surface impedance is only slightly modified (Resonant effect does not appear).

3. EXPERIMENTAL RESULTS FOR THE RECYCLED MATERIALS

The experimental absorption curves, that have been obtained with a standing wave tube for four classes of the material, are represented figure 1. These classes are : a) a large grading coarse mixture (0/14 mm), b) grains lower than 6.3 mm, c) grains lower than 2 mm and d) ranging from 0.38 to 0.52 mm. For the coarse mixture, the absorption curve presents typical alternate maximum and minimum values. As it is, that material is not good enough for the design of sound absorptive barriers. So, finer grading classes have been used in order to follow the evolution of the absorption. Physical characteristics of the material (density ρ, porosity Ω, flow resistivity R_f and tortuosity q) for every class are presented in the following table :

Passing	ρ (kg.m^{-3})	Ω (%)	R_f (Nm^{-4}s)	q
Coarse Mixture	547	51	2500	1.18
< 6.3 mm	536	52	4800	1.17
< 2 mm	513	54	26000	1.16
0.38-0.52 mm	550	50	62000	1.19

Peaks are progressively going smoothing as the grading is restricted to smaller grains. At last, for the finer mixture (< 2 mm), the absorption curve is close to that obtained with rockwool of the same thickness (ρ = 70 kg.m^{-3}).

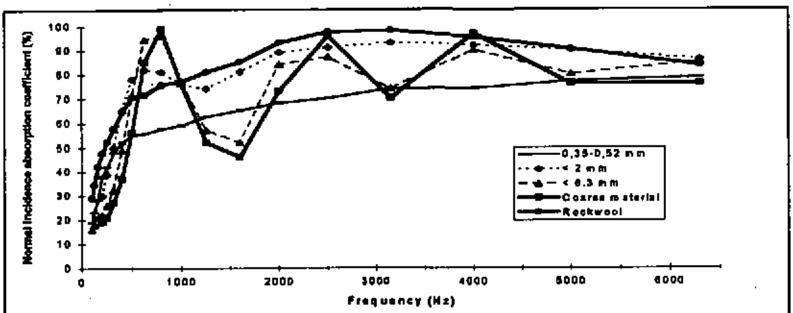

Fig. 1. : Crushed rubber, evolution of the absorption according to the grading.

4. NUMERICAL SIMULATION

In order to model acoustic wave propagation in porous materials, several theories have been proposed [1,2,3]. Here, two theoretical models considering a rigid frame have been used to determine the acoustical properties in that granular material.

Champoux-Stinson Model [3]

This model assumes tortuous non-intersecting pores whose cross section vary along with their lengths. The calculation of the complex density $\rho(\omega)$ and complex bulk modulus $K(\omega)$ require the introduction of two adjustable shape factors s_p and s_k. From these quantities, characteristic impedance and the wave number of the material are calculated. The surface impedance of a layer of granular material covered by a perforated facing is calculated from Ingard-Allard [1,4] theory. Then, the normal incidence absorption coefficient is obtained.

$$\rho(\omega) = q^2\rho_0 + \frac{R_f\Omega}{j\omega}F(\lambda_\rho) \quad \text{with} \quad F(\lambda_\rho) = \frac{1}{3}\frac{\lambda_\rho\sqrt{-j}\tanh(\lambda_\rho\sqrt{-j})}{1-\dfrac{\tanh(\lambda_\rho\sqrt{-j})}{\lambda_\rho\sqrt{-j}}} \qquad (1)$$

$F(\lambda_\rho)$ is the viscous correction function defined by Biot [5].

$$K(\omega) = (\gamma P_0)\left(1 + \frac{(\gamma - 1)}{\lambda_k\sqrt{-jN_{pr}}}\tanh(\lambda_k\sqrt{-jN_{pr}})\right)^{-1} \quad (2)$$

with $\lambda_\rho = s_\rho\left(3q^2\rho_0\omega/\Omega R_f\right)^{1/2}$; $\lambda_k = s_k\left(3q^2\rho_0\omega/\Omega R_f\right)^{1/2}$, N_{pr} the Prandtl number.

Yamamoto-Turgut/Attenborough Model [2,6]

Yamamoto and Turgut have include a distribution of pore sizes e(r) in the viscous correction function :

$$F(\lambda) = \left(\frac{-j\mu\rho_0\omega}{\Omega R_f}\right)^{1/2}\int_0^\infty r^{-1}e(r)\tanh(\lambda\sqrt{-j})dr\left[\int_0^\infty e(r)\left(1 - \frac{\tanh(\lambda\sqrt{-j})}{\lambda\sqrt{-j}}\right)dr\right]^{-1} \quad (3)$$

The pore size is assumed to be a statistical quantity with a log-normal size distribution of tortuous slit-like pores. Their approach has been reviewed and extended to include thermal effects by Attenborough [2]. For a log-normal distribution, we have the following relation :

$$\int_0^\infty e(r)dr = \int_{-\infty}^{+\infty} f(\phi)d\phi \quad \text{with} \quad f(\phi) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(\frac{-(\phi - \bar{\phi})^2}{2\sigma^2}\right) \quad (4)$$

with $\phi = -\log_2(r)$, σ the standard deviation in phi units and $\lambda = r\left(\rho_0\omega/\mu\right)^{1/2}$.

Pore size distribution is an measurable parameter. Thus, the resulting theory does not require any adjustable parameters.

Measurements of Pore Size Distribution

The pore size distribution in the crushed rubber materials has been measured by a water suction method [2]. Figure 2 shows the results of one of these tests (0.38-0.52 mm class). It shows that a log-normal distribution of pores (dotted line) supports the feasibility of describing pore space in crushed rubber with the standard deviation $\sigma = 0.54$ and a mean phi $\bar{\phi} = 2.2$. The continuous line curve is the curve obtained from the experimental data after fitting.

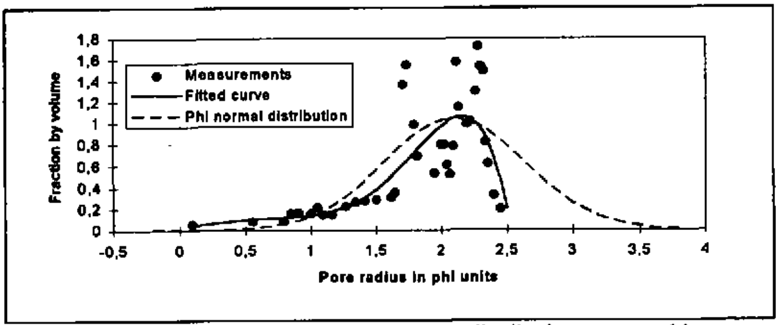

Fig. 2. : 0.38-0.52 mm crushed rubber, pore size distribution measured by a water suction method (points).

Comparison of Model Predictions with Data

Figure 3 shows the surface impedance of panel with 0.38 to 0.52 mm crushed rubber (measured porosity and flow resistivity). The tortuosity has been calculated from the relation $q^2 = \Omega^{-0.5}$ established for stacked spherical particles [7].

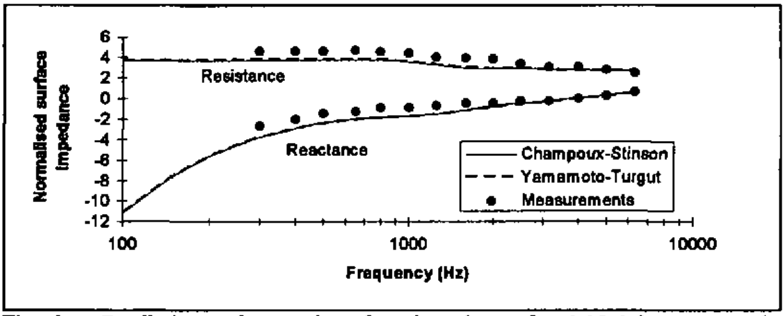

Fig. 3. : Predictions of normal surface impedance for 0.38-0.52 mm crushed rubber.

Predictions for a medium with a log-normal distribution of slit-like pores, with σ = 0.56, give a comparatively good fit with experimental values. The generalised non-uniform pore model of Champoux and Stinson gives the same tolerable predictions with s_p=1.8 and s_k=0.4. Note that the best fit value of the shape factor ratio s_k/s_p is less than unity (0.22 in fact). The ratio is outside the theoretically justifiable range defined by Champoux and Stinson. Results are slightly worse for coarser granulates.

5. CONCLUSION

These two models nearly give the same results and permit to obtain a good tendency of the acoustic properties of crushed rubber. However, the Champoux-Stinson model requires the introduction and adjustment of two shape factors whereas the second model, if the pore size distribution is measured, does not require any adjustable parameters. Likewise, this study has shown that, for the same porosity and density, the acoustic behaviour of crushed rubber is closely linked to the pore size distribution. At last, to obtain an absorption similar to that of a rockwool of the same thickness, it is necessary to use a 0-2 mm mixture.

References

[1] J. F. Allard, Propagation of sound in porous material, (Chapman and Hall, London, 1993), Chapter 10.
[2] K. Attenborough, Acta Acustica, 1, 213 (1993).
[3] Y. Champoux and M. R. Stinson, J. Acoust. Soc. Am., 92(2), 1120 (1992b).
[4] U. Ingard, J. Acoust. Soc. Am., 25(6), 1036 (1953).
[5] M. A. Biot, J. Acoust. Soc. Am., 28(2), 179 (1956).
[6] T. Yamamoto and A. Turgut, J. Acoust. Soc. Am., 83(5), 1744 (1988).
[7] K. Attenborough, J. Acoust. Soc. Am.,73(3), 785 (1983).