Acoustical Investigation of Sintered Highly Porous Metal Fibre Structures as Sound Absorbers

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Abstract

The acoustic behaviour of melt extracted metal fibres and commercially available metal fibres produced by shaving and wire drawing has been investigated experimentally. Sound absorption coefficients and flow resistances have been determined for materials with different porosity and fibre diameter. The influence of the sintering effect on the acoustic properties is taken into account. The experimental data are discussed with respect to literature data of common fibrous absorbers. The theory of homogeneous media can be used to calculate the sound absorption of porous metal fibre structures.

1 Introduction

Sound absorbing materials are extensively used in the field of environmental protection to reduce disruptive noise emission. In the present work the acoustic properties of highly porous metal fibre structures were studied to develop metal fibre structures as effective sound absorbing material (esp. structures consisting of sintered short fibres) with high corrosion resistance, sufficient strength and toughness.

2 General aspects and measuring methods

A sound absorbing material requires an open cell porous structure. The more sound energy enters the porous layer, the more energy may be dissipated. The energy of an incident sound wave on a wall will be divided into a reflected, transmitted, and dissipated part. The reflection factor *r* tends to 1 if the difference between the characteristic impedances $\underline{Z}$ of the two media is high at the reference plane x=0 ($\underline{Z} = \underline{p}/\underline{v}$, is the ratio of the sound pressure to the sound particle velocity). The reflection factor *r* for normal sound incidence is given by $\underline{r} = (\underline{Z}_c - Z_0)/(\underline{Z}_c + Z_0)$ with the complex characteristic impedance of the wall $\underline{Z}_c$ and wave resistance of air $Z_0 = \rho_0 c_0 = 408\ \mathrm{Nsm}^{-3}$ (at 20°C, $10^5\ \mathrm{Nm}^{-2}$), where ρ_0 and c_0 are the density and the sound speed in air, respectively. The reflection of sound waves during passing the surface should be as small as possible. A gradual transition of the airborne sound wave into the absorbing material is advantageous. The frictional motion of the streaming air inside the fine channels of the porous material and impulse losses mainly determine the characteristic impedances and, hence, the frequency dependent sound absorption coefficient α. For plane waves and normal incidence $\alpha(0)$ is calculated by

$$\alpha(0) = 1 - |\underline{r}|^2 = 1 - \left|\frac{\underline{Z}_c - Z_0}{\underline{Z}_c + Z_0}\right|^2 = \left[\frac{1}{2} + \frac{1}{4}\left(\frac{\underline{Z}_c}{Z_0} + \frac{Z_0}{\underline{Z}_c}\right)\right]^{-1}. \tag{1}$$

J. Banhart, M.F. Ashby, N.A. Fleck: *Metal Foams and Porous Metal Structures.* © MIT Verlag (1999)

Due to Eqn. (1) the maximum of $\alpha(0)$ occurs for $\underline{Z}_c / Z_0 \rightarrow 1$. Under the condition that the sound absorbing material is a quasi-homogeneous and viscous medium, the acoustical characteristics are determined by three physical parameters: the porosity σ, the tortuosity χ describing the structure of the absorber, as well as the flow resistance Ξ describing the dissipation within the absorber. The characteristic impedance $\underline{Z}_c$ can be calculated [1, 2] by

$$\underline{Z}_c = Z_0 \frac{\sqrt{\chi}}{\sigma} \sqrt{1 - j \frac{\Xi \sigma}{\omega \rho_0 \chi}}\,, \qquad (2)$$

with the angular frequency $\omega = 2\pi f$. The advantage of the application of the theory of homogeneous medium (THM) is the simple description of a fibrous absorber by only three materials parameters. Other theories [1, 3, 4, 5] describe the real absorber with slightly better accuracy, but the number of parameters is much higher. An empirical relationship between acoustical characteristics and flow resistance divided by frequency is given in [6] and was extended in [7]. The acoustic properties of various metal fibre absorbers were characterized by measuring the sound absorption and flow resistance. The value of the sound absorption coefficient is determined for normal incidence on the object surface by an evaluation of the standing wave pattern of a plane wave in a tube according to ISO 10534-1. The impedance tube method only needs small specimens and is well suited for parameter studies and the design of absorbers. The reflection factor can be written as $|\underline{r}| = (s-1)/(s+1)$, where $s = p_{max} / p_{min}$ is the standing wave ratio at a given frequency (p_{max}, p_{min} - sound pressure maximum and minimum, respectively). Then the sound absorption coefficient can be calculated from Eqn. (1). The frequency dependent sound absorption was characterized at values of the one-third octave band.

The specific flow resistance per unit thickness Ξ (henceforth referred to as the flow resistance) is defined as the ratio of the air pressure difference Δp across a test specimen with the thickness Δx and the velocity v of air $\Xi = -\Delta p / (v \Delta x)$. The flow resistance is determined by a steady volumetric air flow according to DIN EN 29053.

3 Materials, experimental results, and discussion

Table 1 shows the data of commercially available continuous metal fibres with different average diameters d_f produced by wire drawing and shearing as well as short metal fibres produced by the crucible melt extraction process. All metal fibres consist of stainless steel. It should be noted that the cross-sectional geometry of the melt extracted fibres becomes progressively distorted from circular. The form is a half ring at the beginning of the fibre and becomes more kidney-shaped at the end. These fibres are of special interest for the further investigations.

Table 1: Data of selected metal fibre materials

Metal Fibre	*Manufacturer*	*Production Process*	*Cross Section*	*Material*	*d_f [µm]*
Bekipor® 8/300	N.V. Bekaert S.A.	Bundle drawing	Spherical	316L	10
Bekipor® 22/300		Bundle drawing	Spherical	316L	18
STAX-INOX 30g/m	Nakagawa Stax Europe GmbH	Shearing	Rectangular	X6CrMo17.1	65
40g/m		Shearing	Rectangular	X6CrMo17.1	100
CME-fibres	FhG-IFAM	Crucible melt extraction	Kidney-shaped	X5CrNi18.10	200

The measurements were carried out on 50 mm thick metal fibre samples with different bulk densities ρ_a, fibre diameters d_f and sinter states (sintered, non-sintered) to determine their influences on the sound absorption. The increase in the bulk density improves the sound absorption of all kinds of fibres. The same behaviour is experienced if the fibre diameter of samples with similar bulk density decreases. Figure 1 shows that the $\alpha(0)$-values of sintered

CME-fibre samples are less than those of the non-sintered samples. The dissipation of a sintered fibre skeleton is lower than that of the non-sintered fibre absorber because of a change of the inner surface (sinter connections and smoothing of the rough fibre surface have an influence on the tortuosity χ). The influence of the sinter state can be neglected with decreasing fibre diameter. This behaviour might be attributed to a lower influence of the sintering on the inner surface of a fine fibre skeleton. The sintering of various melt extracted metal fibres is described in [11].

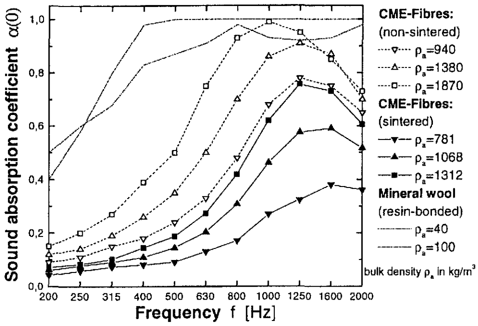

Figure 1. Influence of the sintering effect of CME-fibre samples on sound absorption

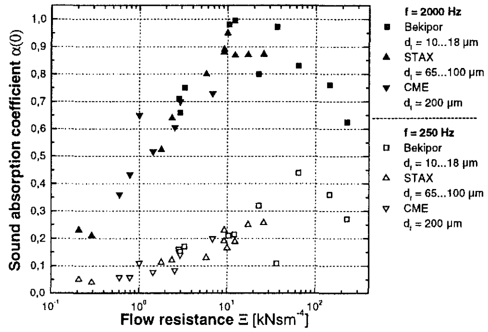

Figure 2. Dependence of the sound absorption coefficient at low and high frequency on the flow resistance

Two curves of a commonly used absorbing material are included in Fig. 1. The comparision shows that the sound absorption properties of mineral wool ($d_f \approx 5\mu m$) are substantially better than those of the metal fibre absorbers.

In Fig. 2 the absorption coefficient at a high and a low frequency of all measured metal fibre absorbers is plotted against the flow resistance. It can be seen that a maximum occurs in each case. It seems that the maximum of sound absorption at f = 250 Hz is slightly shifted to higher values of the flow resistance compared with the sound absorption at the higher frequency. In [8] the quasi-homogeneous theory was used to calculate the optimum flow resistance Ξ_{opt} of metal fibre absorbers to get high sound absorption ($\alpha \geq 0,8$) at $f \geq 1$ kHz and an absorber thickness of 50 mm. The result of this theoretical prediction is a range of $\Xi_{opt} = 8...40$ kNsm^{-4}. The experimental values in Fig. 2 indicate a range of the optimum flow resistance of $\Xi_{opt} = 5...100$ kNsm^{-4}.

In Fig. 3 the measured flow resistances of sintered and non-sintered metal fibre absorbers are compared with their theoretically and experimentally predicted optimum range and with a common glass fibre absorber according to [9]. It shows the importance of the flow resistance as acoustic property (cf. especially the CME-fibre and Bekipor 8/300 samples with $\Xi < \Xi_{opt}$ and $\Xi > \Xi_{opt}$, respectively). Only the fibre absorbers within the marked areas show good acoustic properties. The slight difference between the upper and lower limits of the experimental and theoretical optimum range might be explained by the uncertainty and the scattering of the experimental results. It can be established that the lower the fibre diameter, the lower becomes the bulk density for optimum flow resistance.

A system of 3 layers of metal fibres was used to improve the acoustical properties. In [10] the calculation of the sound absorption of layered porous structures by the THM will be described in detail and compared with experimental data. A layered sound absorber with optimum flow resistance in the middle ($\Xi = \Xi_{opt}$) and lower flow resistance on both sides ($\Xi < \Xi_{opt}$) improves the sound absorption by reducing the sound reflections on the reference plane (cf. Eqn. (1)) and reduces the bulk density esp. of the CME-fibre absorber. The theoretical prediction with $\chi=1.3$ for Bekipor and STAX-fibres as well as $\chi=2$ for sintered CME-fibres ($\chi=3...4$ for non-sintered CME-fibres) coincides well with experimental data. An example of an optimization of a two-layered absorber will be given in [10].

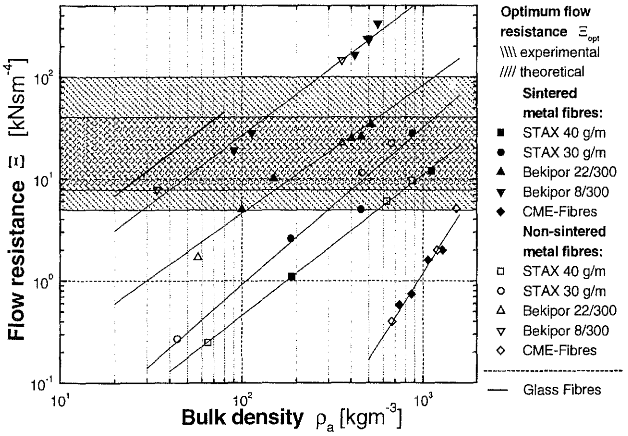

Figure 3. Flow resistance vs. bulk density of metal fibre absorbers

4 Conclusions

Metal fibres can be used to produce sound absorbing materials for special applications. Fine metal fibres are required to get lightweight and effective sound absorbers. The freely suspended or rigidly fixed fibre situations have an influence on the sound absorption. The sintering degrades the acoustic properties of the metal fibre structure. Remarkably, the flow resistance of melt extracted fibres shown in Fig. 3 is more sensitive to the bulk density compared with the other metal fibres. The theory of homogeneous media can be used to predict the acoustical properties of metal fibre absorbers. For special applications, it is useful to have a highly porous metal fibre absorber with superior mechanical properties.

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