inter.noise HAMBURG 2016

Advance in sound absorption and propagation properties of porous metals under harsh environment conditions

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ABSTRACT

To my knowledge, porous metal is a kind of ultra-lightweight (ULW) multifunctional material and has been very widely applied in practical application. Usually most porous metals with open pores are regarded as sound absorbing materials and especially suitable for use in harsh environment. Hence, the recent studies in sound absorption and propagation properties of porous sound absorbing metals have also drawn more and more attention to the acoustic researches under harsh environment conditions. This paper focuses on the advance in sound absorption and propagation properties of porous metals under harsh environment conditions, with particular emphasis on research of sound absorption and propagation in porous metals at high temperatures and sound pressure levels. The corresponding studies are presented for discussion, and the necessary analyses are made briefly.

Keywords: Sound, Porous Metal, Harsh Conditions   I-INCE Classification of Subjects Number(s): 35.2

1. INTRODUCTION

Porous metal is a new type of multifunctional material. Owing to its distinguished advantages in heat resistance, light, stiffness and so on, it has potential applications in noise control in hash environment, such high temperature, and high sound pressure (SPL) [1-3]. At present, porous metal has been widely applied as aircraft engine liners and combustion chambers for rocket or aircraft engines, because of its advantages in harsh environment conditions [4-9]. To my knowledge, most porous metals with open pores are regarded as sound absorbing materials and especially suitable for use in harsh environment. Hence, the recent studies in sound absorption and propagation properties of porous sound absorbing metals have also drawn more and more attention to the acoustic researches under harsh environment conditions. However, much less literature related to the sound absorption and the propagation in porous metal under harsh environment conditions is available elsewhere yet. This paper focuses on the advance in sound absorption and propagation properties of porous metals under harsh environment conditions, with particular emphasis on research of sound absorption and propagation in porous metals at high temperatures and high pressure levels.

2. SOUND ABSORPTION OF POROUS METALS AT HIGH TEMPERATURES

2.1 Uniform Temperatures

As for the case of sound absorption of porous metals under high temperature conditions, in 1976, Christie [10]developed a flow resistance apparatus to measure the sound absorbing properties of a typical mineral wool fibrous material at temperatures up to 500℃. In addition to acoustic impedance and propagation constant the flow resistance of the material was measured over the same temperature range by using an acoustic impedance apparatus. According to this report, good agreement was found between predicted and measured values of the acoustic impedance and propagation constant at various temperatures up to 500℃, with use of a modified form of Delany-Bazley empirical formula [11]. After porous metals were widely applied in practical engineering, Zhang and Chen et al. [1] investigated the sound absorption properties of sintering fibrous metals at high temperatures of 18 to around 500℃, on the basis of Biot-Allard and Johnson-Champoux-Allard acoustic modes. And a high temperature impedance tube testing system was also developed to measure the sound absorbing properties of sintering fibrous metals. The impedance tube testing system is based on two-microphone transfer function method. However, the measured data at lower frequencies are not satisfactory because the temperatures inside impedance tube are not strictly uniform and the assumption for planar acoustic wave in tube could not satisfy rigorously. Aiming at above shortage, Zhang et al. [5] studied the effect of temperature gradient between the front face of porous metal and the microphones in impedance tube on the precision of experimental measurement. Their work shows that the transfer function method can be used, but need to be revised further. Based on aforementioned analysis, they put forward a modified analytic formula to calculate the sound absorption of porous metal at uniform high temperatures. Their study also shows that the impact of temperature gradient on the calculated absorption coefficient can be ignored in the case of small axial temperature gradient. Moreover, to study the effect of high temperatures on sound absorbing properties of fibrous metal materials, Sun et al. [9] theoretically calculated the effective density and effective bulk modulus on the basis of Dupere's model and Tarnow's models. A modifying factor is presented to modify differences between real effective density and the effective density when the fibers were regarded straight. They studied the high temperatures effects on acoustic parameters by thermodynamics theories and variable-property heat transfer.

Williams et al. [8] also explored the sound absorption properties of three fibrous porous materials which have been used in high temperature applications such as automotive and gas turbine exhaust silencers. The authors also constructed an experimental apparatus based on a standard impedance tube that was modified to accommodate temperatures of up to 500℃. Their research shows that measured data for the bulk acoustic properties may be collapsed using a stand Delany and Bazley [11] curve fitting methodology provided one modifies the properties of the material flow resistivity and air to account for a change in temperature. And what's more important, to predict the bulk acoustic properties of a fibrous material at given high temperatures it is necessary only to measure these properties at room temperature, and then to apply the appropriate temperature corrections to the properties of the material flow resistivity and air when using the Delany and Bazley formulae [8].

In addition, Rademarker et al. [7]built a facility for hot steam liner testing up to a flow Mach number of 0.4 and a maximum temperature of 500℃; it is noted that the hot steam liner is applied for acoustic treatment in exhaust ducts of turbofan engines. Elnady et al. [6] studied the temperature effect on the impedance and it was found from their work that the temperature effect on the impedance can be predicted quite well by changing the fluid properties (density, viscosity and speed of sound).

In fact, according to our present researches, the same conclusion is also suitable for the case of using the Biot-Allard and Johnson-Champoux-Allard acoustic models [13]. Figures 1-3 are the acoustic results for a porous metals at high temperature of 500℃.The acoustic parameters are listed in Table 1.

Table1 – Acoustic parameters of a porous metal

No.	Viscous factor	Thermal factor	Thickness /mm	Tortuosity	Resistivity /$Nm^{-4}s$	Porosity
#1	1.6620	0.6288	25	1.664	20610	90

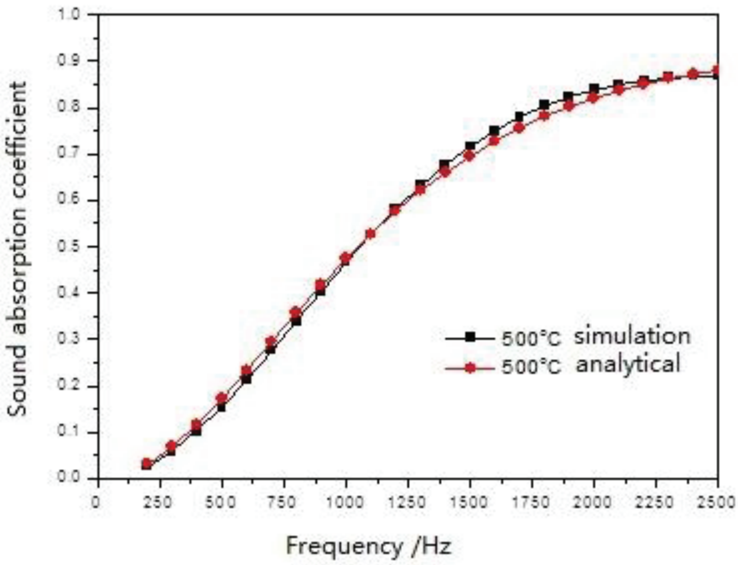

Figure 1 – Sound absorption coefficient of porous metal #1 at temperature of 500℃.

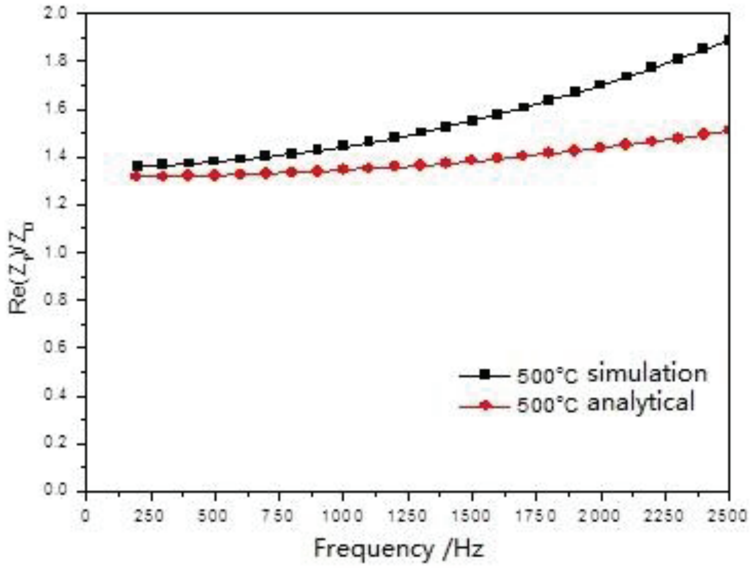

Figure 2 – Specific acoustic resistance of porous metal #1 at temperature of 500℃

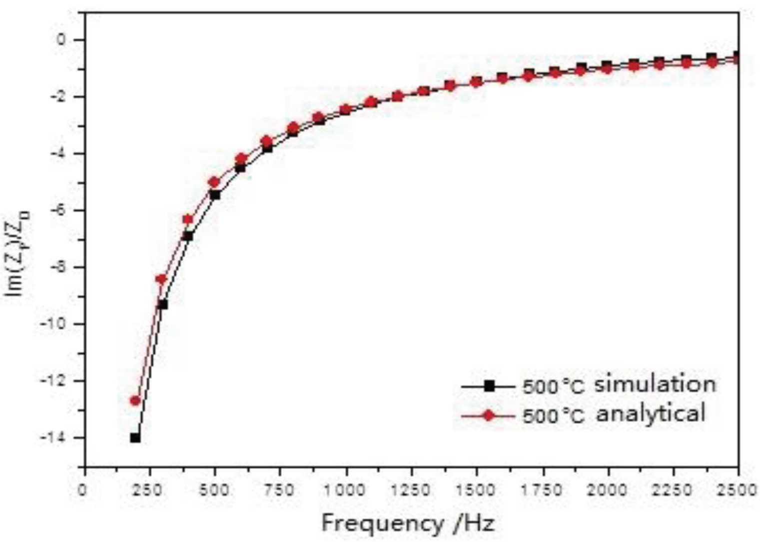

Figure 3 – Specific acoustic reactance of porous metal #1 at temperature of 500℃.

2.2 High Thermal Gradient

In above-mentioned works, the temperature that a porous material experience is regarded as uniform value in most cases. High thermal gradient is not considered yet. However, as indicated by Elnady et al.[6], if a thin sheet of porous material is added to the perforated top sheet, which is not uncommon in practice, this combination may exhibit additional high temperature effects caused for instance by structural effects in porous material. They also presented several temperature distributions inside the cavity along the distance away from the back plate. In this case, the effect of different high thermal gradients on sound absorbing is not avoidable. According to this situation, Zhang and Chen et al. [1] evaluated the sound absorption properties under different temperature gradients (-2.4℃/mm and 4.05 ℃/mm), focusing the attention on a sintered fibrous metal sample (see Fig.4). It has been found that the changes of temperature fields exert remarkable effects on the surface acoustic impedance at normal incidence of material. When the constant temperature gradient exists across the materials cross-section, the effects of temperature gradient on overall sound absorption characteristics of porous metal ought to be regarded considerably. Under certain conditions, the negative temperature gradient may enhance the sound absorption of porous metal whereas the positive temperature brings an adverse effect.

In addition, Gasser et al. [12] presented an experimental set-up to investigate the influence of thermal gradient on acoustic absorption of a sound absorbent. Their previous research also indicated that a thermos-acoustical effect may occur at low frequencies when the liner experiences a thermal gradient of about 100 K/cm, which is the expected order of magnitude for a liner of a few centimeters thickness placed in a turbo-engine exhauster. In our previous work, the measuring precision at lower frequencies for the high temperature impedance tube we designed was not satisfactory also. Maybe this phenomenon is due to a thermos-acoustical effect during measurement. In particular, thermos-acoustical effect is more apparent when exerted thermal gradient is large enough.

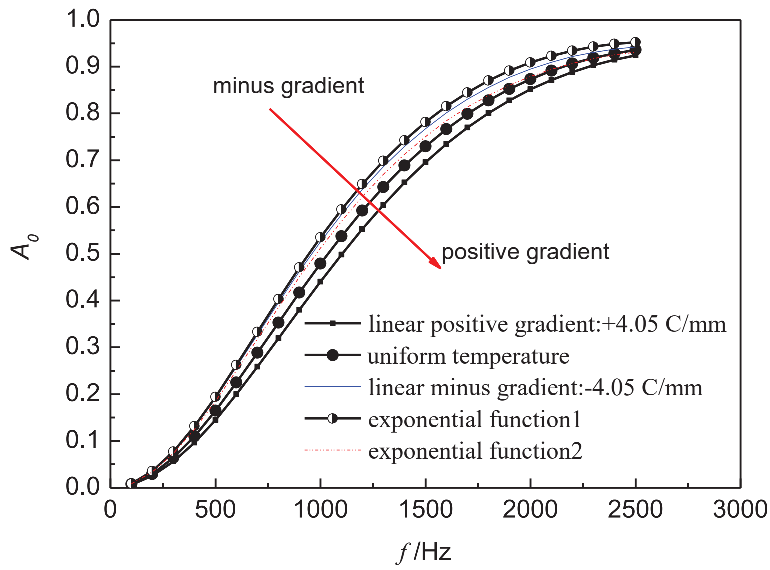

Figure 4 – Sound absorption coefficient of porous metals under different temperature field conditions [Ref.4]

3. SOUND ABSORPTION OF POROUS METALS AT HIGH SOUND PRESSURES

In fact, the sound propagation and absorption properties of porous media at high sound pressure levels have been studied by a number of authors. For example, Thurston et al. [14] and Ingard and Ising [15] have studied high intensity sound propagation and absorption for perforated sheets. Zorumski and Parrott [16] presented the concept of temporal impedance in their theoretical and experimental studies on the acoustic nonlinearity in rigid porous materials. Kuntz and Blackstock[17] pointed out that acoustic losses inside porous materials are so large that waveform distortion produced by the acoustic nonlinearity is negligible, but excess attenuation and saturation still occur and can be regarded as an entirely different acoustic nonlinearity. According to their researches, the acoustic nonlinearity and the excess attenuation inside the porous materials may be predicted directly from dc flow resistivity data. Here it should be noticed that porous metal is a type of rigid porous material. Therefore, all sound absorbing conclusions related to rigid porous material is suitable for porous metal as well.

In terms of the sound absorption and propagation of rigid porous material at high sound pressure levels, the most important contributions were made by Wilson et al. [18], and Lambert and McIntosh [19]. Wilson et al. [18] considered the nonlinear effects of the Forchheirmer-type through a complex density operator and developed a simplified nonlinear theory, which is an extension of the classical rigid frame theory. Their further studies showed that there two flow regimes for air in rigid porous materials: at low velocities, the resistance coefficient increases with the square of the fluid velocity; at high velocities, the resistance coefficient increases linearly with the fluid velocity. Auregan and Pachebat [20] measured the flow resistivity of rigid porous materials and observed the two types of nonlinear behavior, which depend on the Reynolds number. Wilson et al. also [18] come up with a numerical solution for nonlinear wave propagation and attenuation inside rigid porous materials restricted to pure tone excitation. Other authors [21] have carried out the similar works to predict the sound absorbing properties of rigid porous materials including perforated sheets at high sound pressure levels. In my view, the solution of Wilson et al. [18] is still regarded as the best model up to date. Lambert and McIntosh [19] also brought forward an approximate analytical solution for surface acoustic admittance using a wave perturbation method for infinite rigid porous materials at high sound pressure levels. Following the works of Wilson et al. [18] and Lambert and McIntosh [19], Zhang et al. [22] proposed an approximate analytical solution for the normalized surface acoustic admittance of rigid air-saturated porous materials with infinite thickness based on the wave perturbation method developed by Lambert and McIntosh [19]. The comparison with numerical solutions in their work shows that the approximate analytical solutions improved the accuracy for predicting the nonlinear acoustic admittances of infinite porous media, especially at lower frequencies. Umnova et al. [23] conceived a model for the propagation of high amplitude continuous sound through a hard-backed rigid porous layer, based on a modified equivalent fluid model by introducing a flow velocity dependent flow resistivity. According to their report, this model is mainly suitable for acoustic wave with slow varying amplitude.

Recently, it should be noticed that Wu et al. and Zhou et al. [2-3] presented a quantitative theoretical model to investigate the sound absorbing property of porous metal materials with high temperature and high sound pressure based on Kolmogorov turbulence theory. They thought that porous materials have a large number of anomalous pores with similar scale, and these irregular pores could be considered as quasi-periodic structure that was very similar to the small-scale turbulence. Therefore, Kolmogorov turbulence theory was adopted to analyze the wave propagation inside the porous metals materials, in which the characteristic velocity and characteristic scale can be obtained by the non-dimensional analysis method. Their further studies showed that the acoustical pressure amplitude in the porous metal materials under temperature and high sound pressure level can be figured out with respect to metal wire diameter, porosity, and other parameters. The developed model may deal with the evaluation of the sound absorption of porous metals under harsh environment conditions of high temperatures and high sound pressure levels, and more attention should be paid to. Figures 5-6 show the results obtained by using model of Wu et al. and Zhou et al. [2-3]

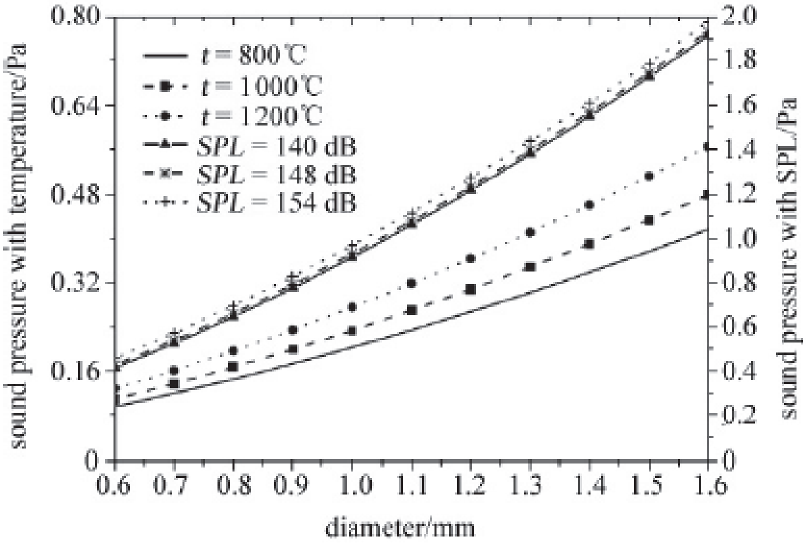

Figure 5 – Sound pressure for different values of wire diameter, at different temperatures, and at different incident pressure levels, respectively [Ref.2].

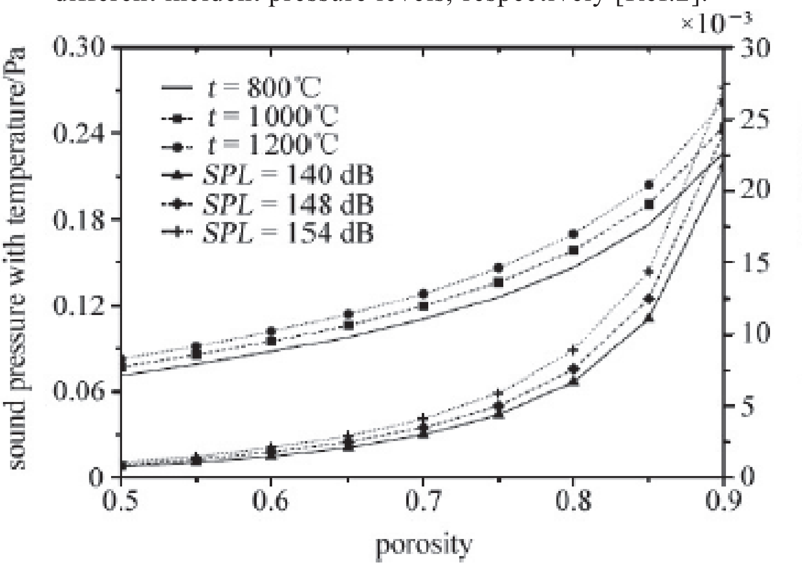

Figure 6 – Sound pressure for different values of porosity, at different temperatures, and at different incident pressure levels, respectively [Ref.2].

4. SUMMARY

In this paper, recent advance in sound absorption and propagation properties of porous rigid materials mainly focusing on porous metals under harsh environment conditions are introduced with particular emphasis on the research of sound absorption and propagation in porous metals at high temperatures and pressure levels. It has been found that some acoustic models and approaches have been developed. Especially, the model by Wu et al. and Zhou et al. [2-3] should be paid more attention as one evaluates the sound absorption properties of porous metals at high temperature and high pressure sound levels in practical noise control applications. For the case of uniform high temperatures, the temperature effect on the impedance of porous metals can be predicted quite well by directly changing the fluid properties (density, viscosity and speed of sound) and so building corresponding experimental apparatus is not necessary to an extent. In addition, the two-microphone transfer function method can be used to measure the sound absorption properties of porous metal at uniform high temperatures; however, minor improvement for data processing should be made due to the effect of temperature gradient inside impedance tube. Moreover, for large temperature gradient existing along axis of tube, thermos-acoustical effect should be considered for the measurement of sound absorbing of porous metals at lower frequencies.

ACKNOWLEDGEMENTS

The author gratefully acknowledges support for this work from the Project of National Natural Science Foundation of China (grant No.51365046).

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