Influence of static compression on mechanical parameters of acoustic foams

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(Received 18 October 2010; revised 24 February 2011; accepted 24 May 2011)

The modification of elastic properties of compressed acoustic foams is investigated. The porous sample is first submitted to a static compression and then to a dynamic excitation of smaller amplitude, corresponding to acoustical applications. The static compression induces the modification of the dynamic elastic parameters of the material. This work focuses on Young's modulus. The variation is measured with two different experimental methods: The classical rigidimeter and an absorption measurement. The effective Young's modulus is directly measured with the first method and is indirectly determined through the quarter-wave length resonance of the frame with the second one. The results of the two measurements are compared and give similar tendencies. The variation of the dynamic Young's modulus as a function of the degree of compression of the sample is shown to be separated in several zones. In the zones associated with weak compression (those usually zones encountered in practice), the variation of the effective Young's modulus can be approximated by a simple affine function. The results are compared for different foams. A simple model of the dependency of the Young's modulus with respect to the static degree of compression is finally proposed for weak compressions. © *2011 Acoustical Society of America*. [DOI: 10.1121/1.3605535]

PACS number(s): 43.55.Ev, 43.20.Gp, 43.20.Hq [FCS] Pages: 818–825

I. INTRODUCTION

Acoustical porous materials (or sound absorbing materials) are heterogeneous media made up of an elastic skeleton saturated by a fluid (air in the present case). Structures involving porous materials are commonly used in engineering applications to dissipate acoustical or mechanical energy (sound and vibration absorption or insulation, damping). The modeling of porous materials is generally made at the macroscopic scale, so that the heterogeneities can be averaged over a representative elementary volume. Hence, the formalism of continuum mechanics is employed. Two classes of homogenized models are used to describe the dynamic behavior of poroelastic materials: The equivalent fluid model,[1] when the solid is assumed to be rigid and motionless, and the Biot theory,[2] when the frame is deformable. The Biot formalism needs two categories of characteristic parameters: Acoustical and mechanical. The determination of the acoustic parameters is now well handled, while the mechanical characterization of poroelastic materials has been a subject of research in the last decades.

The experimental methods used to determine mechanical (or effective elastic moduli) parameters of porous materials can be classified into three categories: Resonant methods, techniques based on surface waves, and quasi-static methods. An exhaustive list of the current available techniques for the recovery of elastic and damping parameters of porous materials can be found in Ref. 3. The limits of each method and the conditions of their application are clearly stated.

A resonant method was proposed in Ref. 4 to determine the effective Young's modulus of a sample at its resonance frequencies using a displacement transfer function measurement and a one-dimensional solid wave equation estimation. Methods derived from the Oberst beam method can also be used for bending vibrations.[5]

At higher frequencies, methods based on surface waves include the Rayleigh wave based method[6] and guided waves based methods.[7,8] Both of them enable the determination of the porous sample shear modulus, either from the Rayleigh velocity or from the minimization of the difference between the calculated dispersion curves and the measured ones obtained from Fourier transformation of the surface displacement standing waves. Quasi-static methods[9] are used at low frequencies to determine the effective elastic modulus.

One major difficulty for the characterization of mechanical parameters of poroelastic materials yields is in the large sensitivity of these parameters to various experimental or *in situ* conditions. Among them, Pritz[4,10–12] points out the influence of a weak static compression on the elastic parameters and also for higher degrees of compression. Nevertheless, only preliminary and qualitative results were carried out for very weak compressions. The influence of the compression on the acoustic parameters of fibrous materials, modeled by use of the equivalent fluid model, has been studied by Castagnýde *et al*.[13,14] It was then extended to the Biot theory in Ref. 15 without accounting for the influence of compression on the mechanical parameters. Hence there is a need to go further and to focus on this aspect. This phenomenon is mainly sensitive for foams that are soft materials and composed of a open microstructure. The static compression induces a modification of the beams that compose the microstructure (deformation and bending). Moreover, sound absorbing materials are usually compressed in practical application. This compression can be due to their layout (aircraft fuselage, building ceiling, trims) or their use (automobile seats).

The influence of the compression of open-cell porous materials has also been observed in the context of mechanics.[16–18] These works are devoted to geomaterials, and their results can not straightforwardly be applied to acoustics foams (dimensions, type of sample, excitation, experimental conditions). It is one objective of the present work. Hence, there is a need of investigating the influence of static compression on mechanical parameters of porous foams. It can explain the discrepancies and differences that can be observed during the mechanical characterization of porous foams.

The present work focuses on the experimental study of the influence of static compression on the dynamic Young's modulus of acoustic foams. For this type of medium, the volume of closed cell is negligible compared to the one of open cell, so that the contribution of closed cell in the mechanical behavior of the frame can be neglected. Two types of experiments are considered. Quasi-static measurements are first performed with a rigidimeter.[9,19–22] This setup has been modified and automated in the framework of this work. The corresponding measurements are referred to in this paper by the term "mechanical" and directly provide the Young's modulus of the frame sample. Absorption measurements ("acoustical" bench) of a compressed porous sample are second performed with an impedance tube. The deformation of the porous frame is mainly sensitive at the so called quarter-wavelength resonance of the solid wave.[1,23] From this frequency, it is possible to indirectly determine the Young's modulus. The results are compared and analyzed, and a simple model for the dependency of the dynamic Young's modulus in terms of weak degree of compression is proposed.

II. TOPICS ON COMPRESSION OF POROUS MATERIAL

Dynamics and deformation of porous material is generally modeled through the Biot theory.[2] The porous medium is considered as the superposition of two homogeneous phases, a solid and a fluid one, that mutually interact. Several formulations[2,24–26] of the Biot theory, which differ by the unknowns employed to describe the medium response, have been proposed. All of them employ the displacement of the solid phase. Stresses and strains are tensors and are linked to each other by coupled constitutive relations. The mechanical parameters are associated with the stress tensor of the solid phase.

For our purpose, it is more convenient to use an equivalent solid model. This means that experimental conditions should minimize the influence of the saturating fluid. For the mechanical bench, precautions on the amplitude and frequency of the perturbation process need to be taken to satisfy these conditions. They mainly depend on the flow resistivity of the material, which quantifies the solid-fluid coupling. Hence, the perturbation process is designed to let the air escape from the material.[9,27] For the acoustical bench, it is impossible to totally satisfy these conditions. Nevertheless it can be reasonably assessed that the fluid properties of foams are not slightly modified by the compression because only relative variation will be considered in this work.

The solid displacement $\mathbf{u}$ is the sum of the static displacement $\mathbf{u}^\tau$ and the dynamic displacement $\mathbf{u}^d$. Small perturbations of $\mathbf{u}^d$ around the static equilibrium induced by $\mathbf{u}^\tau$ are assumed. The deformation tensors are denoted by ε_{ij} and the stress tensors by σ_{ij}. The Einstein convention is implicitly used in this manuscript.

Large deformations, associated with $\mathbf{u}^\tau$, are considered. The stress-strain relation is of the following form: $\sigma_{ij} = f(\varepsilon_{ij}^\tau, \varepsilon_{ij}^d)$, with f being a non-linear function. For small amplitude of the dynamic perturbations $\mathbf{u}^d$, this equation can be rewritten as:[28]

$$\sigma_{ij}(\varepsilon_{ij}^\tau, \varepsilon_{ij}^d) = \sigma_{ij}^\tau(\varepsilon_{ij}^\tau) + \sigma_{ij}^d(\varepsilon_{ij}^\tau, \varepsilon_{ij}^d), \tag{1}$$

where the static stress σ_{ij}^τ only depends on ε_{ij}^τ (Ref. 29), and the additional stress due to the dynamic perturbation is denoted by $\sigma_{ij}^d(\varepsilon_{ij}^\tau, \varepsilon_{ij}^d)$. Under the hypothesis of small perturbations, the dynamical stress-strain relation is modeled as:

$$\sigma_{ij}^d(\varepsilon_{ij}^\tau, \varepsilon_{ij}^d) = C_{ijkl}^d(\varepsilon_{ij}^\tau)\varepsilon_{kl}^d, \tag{2}$$

where $C_{ijkl}^d(\varepsilon_{ij}^\tau)$ is the Christoffel matrix, whose elements depend on the static compression.

In the present work, static and dynamic perturbations are mainly mono-dimensional and are applied along the x-direction, which corresponds to the thickness of the sample. In the other directions, the dimensions are supposed infinite because of the monodimensional hypothesis. The initial thickness of the sample is L_0. After compression, the sample thickness is L and the degree of compression τ is defined by:

$$\tau = \frac{L_0 - L}{L_0}. \tag{3}$$

For mono-dimensional deformation, only σ_{xx}^d is relevant and Eq. (2) reduces to

$$\sigma_{xx}^d(\tau, \varepsilon_{xx}^d) = E(\tau)\varepsilon_{xx}^d, \tag{4}$$

where in $E(\tau)$ is the dynamic Young's modulus.

The aim of this paper is to measure and model the dependence of $E(\tau)$ for several foams.

III. EXPERIMENTAL SETUP

A. Mechanical experimental setup

Due to the large number of measurements to be performed, the mechanical bench presented in Ref. 9 has been modified for the purpose of this work. Each element of the bench is now controlled from a computer with a GPIB protocol and an OCTAVE (Ref. 30) script. It is depicted in Fig. 1. A 4 cm edge cube of porous material is inserted between two plates. The upper plate is connected to a rigid structure and assumed to be fixed. The

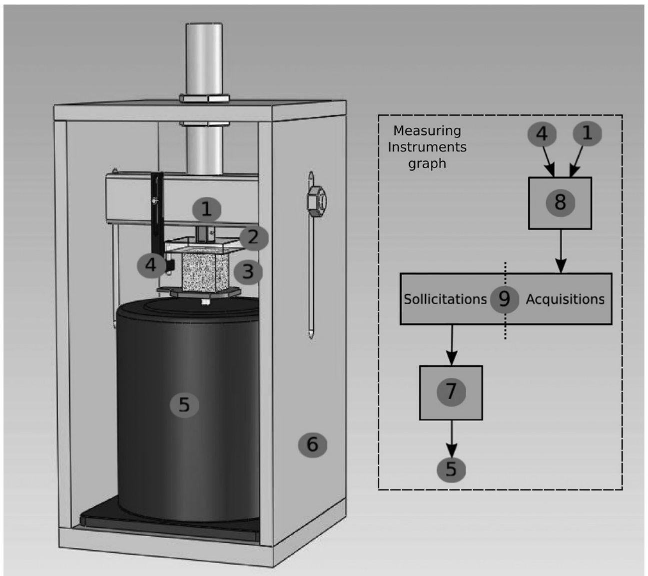

FIG. 1. Mechanical setup: (1) strength sensor PCB 209B01, (2) rigid plate, (3) acoustic foam, (4) displacement sensor Keyence EX-201/305, (5) shaker Bruel and Kjaer type 4808, (6) rigid structure, (7) signal generator Agilent 33120A, (8) scope meter Waverunner, amd (9) computer.

lower plate imposes the static and dynamic excitations. It is controlled by a shaker (Bruel and Kjaer type 4808) powered by a signal generator (Agilent 33120A). The experimental setup is an extension of an existing bench that was designed to provide an uni-axial deformation on the cube (the plates are mutually parallel and centered at the same axis); this explains the choice of the dimensions of the cube. $E(\tau)$ needs to be measured for various degrees of compression τ. The different measurements only differ by the static excitation amplitude applied to the sample. For the sake of clarity, the experimental process is only presented for one degree of compression.

A static excitation (Heaviside function signal, assumed to be constant during this step) associated to the compression of the sample is first applied. The foam thickness L is measured to evaluate the degree of compression τ. A dynamic excitation is then applied to the sample in the form of a sinusoidal signal added to the static one. The dynamic strength F^d is measured with a strength sensor (PCB 209B01) located on the top of the upper plate, and the displacement of the lower plate u^d is measured with a displacement sensor (Keyence EX-201/305). The signals are acquired during the dynamic excitation with an scope meter (Waverunner), and the effective elastic modulus E of the homogeneous sample is obtained by:[9,22]

$$E = \frac{F^d L}{u^d S}. \tag{5}$$

The section S of the foam between the two plates is assumed to remain constant for each static compression step at its initial value $S = S_0 = 16\ \mathrm{cm}^2$. Note that in Eq. (5) the thickness of the sample is L as it corresponds to the thickness of the sample in the actual compressed condition. F^d and u^d are averaged over five periods. From our experience, doing an averaged of five periods is sufficient to have a correct estimation of the parameters.

The ratio of dynamic to static excitations has been chosen to respect the recommendation of the literature.[3,4,9] Each set of measurements has been performed in a relatively short period to ensure that the temperature can be assumed constant. The latter does not influence the relative results presented in the following. To avoid any problem related to the sample-plates conditions, the plates are covered with an abrasive paper,[9,19] which deletes relative plate-sample displacements. This solution is preferred to the use of glue because the contact location along the x-direction is better controlled.

It is necessary to ensure that the experimental process is not influenced by the foam relaxation. The objective is to guarantee that the mechanical excitation is transmitted through the foam with a response time short enough to neglect the imaginary part of effective elastic modulus. This means that the foam reaction time to an impulsive perturbation is sufficiently small when compared to the period of the dynamic excitation. For materials with a longer time of relaxation, the preceding definition is irrelevant. Each compression step is recorded by a camera (25 frame/s), and a homemade multi-frame tracker algorithm similar to the one in Ref. 31 is used. A regular squared mesh of points is drawn on the surface of the sample. The relaxation average time is defined as the time after which the points return to their initial positions. After averaging, the relaxation time is estimated for the melamine foam to be around 20 μs.

The origin for the static compression should be precisely defined. Indeed, if the contact is not ensured between the sample and the plates, the signal is not properly transmitted through the foam. A criterion to quantify this is to check the quality of the strength sensor signal, which should be sinusoidal. Both u^d and F^d signals are visualized on the scope. u^d is always sinusoidal, and distortion is observed for F^d in the case of unsuitable contact. Note that this value does not correspond to the theoretical situation of the uncompressed sample (F^d is zero per half period) because such condition can not be reach experimentally. Fortunately, these values are very close (less than 1 mm).

B. Acoustical experimental setup

The acoustical setup is based on the impedance measurement setup proposed by Dalmont *et al.*[32,33] and commercialized by CTTM.[34] It is depicted in Fig. 2. The principle is to determine the absorption coefficient of the foam sample from the measurement of the transfer function between the two microphones.[32,33] A piezo-electric buzzer, used for the excitation, is placed between a closed cavity and a measurement pipe. The pressure in the cavity is measured with a microphone and is proportional to the velocity. The pressure at the input of the pipe is measured with a second microphone. The surface impedance is then obtained from the transfer function measurement between these two microphones. The absorption coefficient is deduced from the surface impedance measurements by classical formula.

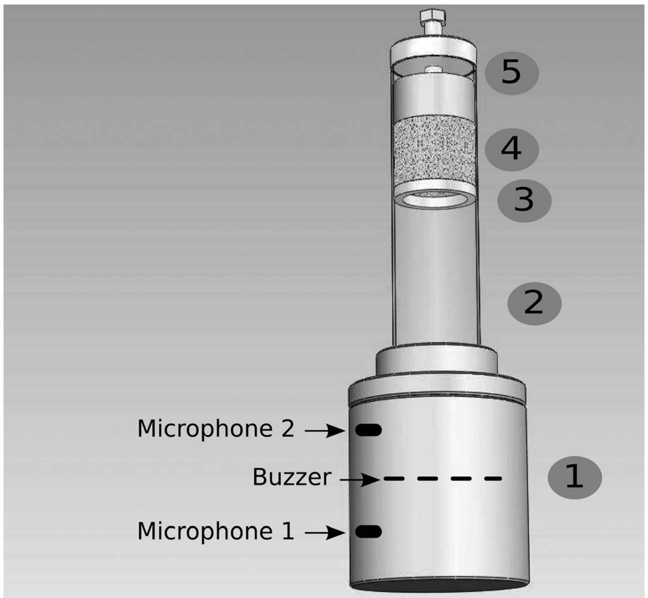

FIG. 2. Acoustic absorption measurement setup: (1) acoustic impedance bench, (2) pipe, (3) fixed ring, (4) foam sample, and (5) adjustable piston.

One of the main advantages of this setup is that the frequency range of the measurement is wider than the one of a classical impedance tube, which is limited in low frequencies by the distance between the two microphones. In particular, this setup enables low frequency measurements down to 100 Hz. To perform experiments for different degrees of compression of the porous sample and to control them, a 2-mm-thick ring is rigidly fixed inside the tube inner portion at 5.5 cm from the end of the tube. The material is placed between this ring and a rigid flat condition piston of thickness 2.5 cm, thereby compressing the sample against the ring. The piston is placed at the end of the tube, and its depth is controlled by a screw (thread: 1 mm). The initial thickness of the foam sample is $L_0 = 3$ cm, and the inner diameter of the tube is 3.5 cm.

The air-porous surface of the sample needs to be flat to perform the impedance measurements and to ensure the plane waves condition. Due to the ring, the surface of the sample in contact with the ring could be modified when the sample is compressed by the piston against the ring. It is difficult to experimentally determine this modification. A numerical study, based on axisymmetric poroelastic finite elements, not detailed in this manuscript for conciseness, has been performed for compression associated to compression rates lower than 0. 1. It indicates that it slightly modifies the absorption coefficient, but the differences are lower than 0.05 and can then be neglected.

The variation of Young's modulus $E(\tau)$ is determined by an indirect method. This method is based on the so called quarter wavelength resonance of the frame. At this frequency and for this type of material, the absorption decreases due to a loss of viscous effects. This resonance can then be easily seen on absorption curves, and it is possible to estimate the associated frequency. This frequency can also be estimated by an analytical expression given in Ref. 23, which provides a link between this frequency and the mechanical parameters:

$$f(\tau) = \frac{1}{4L2\pi}\sqrt{\frac{E(\tau)}{\rho(\tau)}}, \tag{6}$$

wherein L is the thickness of the compressed foam sample. The density of the solid is $\rho(\tau)$. The mass of the sample is independent from compression so that the density is proportional to $1/L$. It is then possible to estimate the ratio of the Young's modulus of the compressed material and the one at the origin of static compression:

$$\frac{E(\tau)}{E(0)} = (1-\tau)\frac{f(\tau)^2}{f(0)^2}. \tag{7}$$

Relative variations of the mechanical parameter can then be indirectly measured from the variation of quarter wavelength resonance frequency.

IV. RESULTS AND DISCUSSION

A. Evolution of $E(\tau)$ for a large range of degree of compression

A sample of melamine foam (named in the following as the reference foam), which is widely used in anechoic rooms, is first considered. This melamine foam is industrially produced, and its properties are given by Boeckx[35] and reported in Table I. The manufacturing process is not known.

That sample is used with the mechanical setup for a degree of compression from the origin to 0.7. This final value corresponds to the limit of use of the bench. Figure 3 presents the evolution of a normalized Young's modulus as a function of the degree of compression. This non-dimensional mechanical parameter corresponds to the ratio $E\tau/E_{max}$ where $E_{max} = E(0.03)$ is the maximum value of $E(\tau)$ on the compression range of interest. The dependency of E with τ can be split into four zones (respectively named A, B, C, and D) and can be interpreted with the micro-structural approach presented in Refs. 18 and 36.

Zone A (compression from the origin to 0.03 corresponding to the maximum value of Young's modulus) is associated with the compression of the cells that compose the microstructure of the foam. No bending of the beams is involved in this zone. The elastic modulus varies between 0.45 and 1. This means that the value $E(0.03)$ is

TABLE I. Measured material properties.

Parameters	ϕ	t (m)	p (kgm^{-3})	α_∞	σ (Nsm^{-4})	Λ (ym)	Λ' (ym)	E (KPa)	N (KPa)
	> 0.95	0.03	10	1.01	12000	100	150	$600 + 6i$	$250 + 20i$

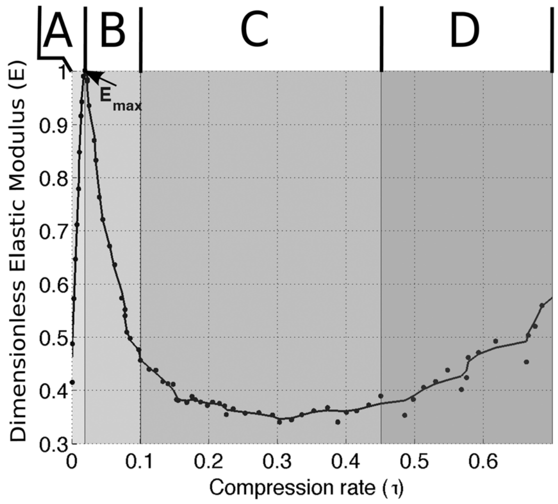

FIG. 3. Variation of Young's modulus of reference foam for a large range of compression: zones determination.

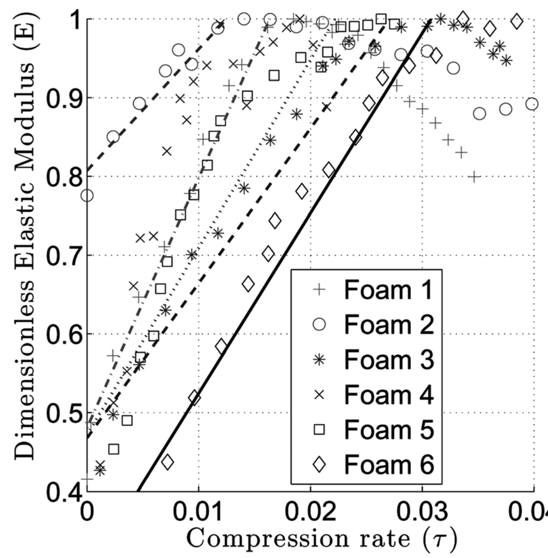

FIG. 4. Young's modulus of the six foams in Zone A compression band: linear behavior.

approximately twice as the one at the origin. This phenomenon is linked to the material that constitutes the beams. It corresponds to a slight compression (corresponding for the considered sample to a thickness modification of 1.2 mm). This zone has been observed by several authors.[3,19,20,37] In Refs. 20 and 37 (resp. Refs. 3 and 19), the ratio is around 3 (resp. 1.9) for a degree of deformation between 2.10^{-3} and 0.02 (resp. 4.10^{-3} and 0.02). This zone is deeply investigated in Subsection IV B.

Zone B is associated with degrees of compression from 0.03 to 0.1. It is associated with the bending of the beams that constitute the micro-structural cells, which are collapsing. This phenomenon is linked at the geometry of the beam. This zone has not been studied by the previous works to our knowledge. This zone is of great interest for two reasons. The first one is that it corresponds to the case of usual applications. For a sample of 4 cm, it is reasonable to assume that *in situ* compression would greater than 1.2 mm. The second one is that it is associated with a loss of elastic properties around 0.6, which is far from being negligible. In addition, it is observed that the variation can be easily fitted by a linear interpolation. This zone is deeply investigated in Subsection IV C.

Zone C (degrees of compression between 0.1 and 0.45) corresponds to the plateau regime over which $E(\tau)$ is relatively constant. The elastic buckling of the beams are counterbalanced with the effect of the cells network, and then the brittle crushing occurs in the direction of static stress compression. Zone D corresponds to densification regime. The elastic modulus increases.

The elastic modulus increases. The microstructure is completely collapsed, and opposed microstructure edges come in contact with each other. Note that the experimental curve only presents the beginning of the densification regime because of the limit of the bench.

Some remarks need to be made to avoid some generally accepted ideas. The first one is that the compression of the foam is not uniform along the thickness of the sample. This has been visually observed in the framework of this work and has been also observed by Guastavino and Göransson.[38] Hence, the splitting of the four zones presented in the previous paragraph should be done with particular care. Indeed, it is not straightforward that the geometry of all the micro-structural cells of the sample are similarly modified. It is more believable that some of them change regime before the others. A second remark is that the curve presented in Fig. 3 is not the derivative of the stress-strain relation, so that the acoustical dynamic Young's modulus is not the local slope of the stress-strain curve. One reason is the non-uniformity of the deformation presented before, and a second one is that the strain-stress relation is not in the small strain regime as is the case for acoustical perturbation.

In the following, only zones A and B will be detailed as they correspond to classical sound absorbing applications. Contrary to the higher degree of compression zones, which can be associated with a degradation of the microstructure (crack or rupture of micro- structural edges), these two zones should preserve the integrity of the skeleton. It has been checked by iterative measurements after several compression-decompression cycles and exhibits the repeatability of our experiments. The experiments have been performed on six foams, representative those currently available in the laboratory. These foams correspond to a wide range of industrial polymeric foam. The manufacturing process and the properties of these foams are unknown. The samples preparation has consisted of the cutting of the foam with a bandsaw.

B. "Compression of beam" regime (Zone A) for different foams

The "compression of beam" regime is presented in Fig. 4. For each foam, the Young's modulus increases. Each

TABLE II. Material classification in function of the compression slope on Zone A.

Foam	1	2	3	4	5	6
Slope	31.74	15.43	19.66	31.49	23.81	22.86

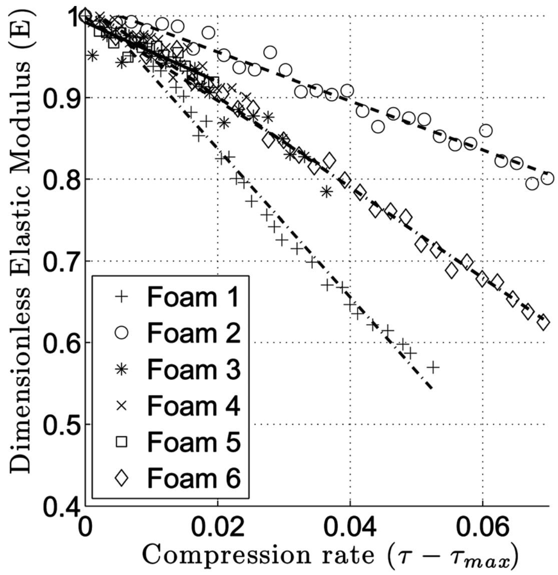

FIG. 5. Young's modulus of the six foams in Zone B compression band: new origin.

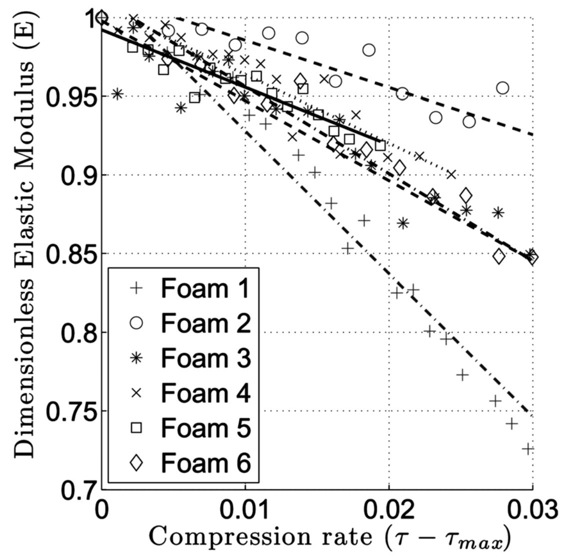

FIG. 6. Zoom of Zone B compression band: linear behavior.

variation can be approximated by a linear regression. The slopes are presented in Table II. There is relatively small variability in these slopes (between 15 and 31); this indicates a similarity between all the materials. This can be explained by the fact that all the materials are polymeric foams and thus have similar constitutive material and micro-geometry.

Contrary to the slopes, the transition between zones A and B occur for degrees of compression between 0.015 and 0.03 for the different samples. This indicates the variability of this parameter. It can be explained by the difference of the representative cell dimension of the foams. The bending transition is very sensitive to the height of the beams. Consequently, the transition for large cell materials occurs for a degree of compression lower than the one of small cell materials. The prediction of the transition from zone A to zone B is a complicated problem. It is surely an extension of the present work. In any case and for all of these materials, the experimental results indicate that zone A corresponds to very small degrees of compression (lower than 0.03).

C. Bending regime (Zone B) for different foams

Zone B is now investigated for the same foams as in the previous section. For each foam, and to simplify the comparison between the curves, the reference of degree of compression has been chosen equal to the degree of compression $\tau_{\max}$ associated with the maximum $E_{\max}$ of the normalized Young's modulus. Consequently, all the curves have a unit value at this new origin. Results are presented in Fig. 5 and detailed on the [0;0.03] new degree of compression range in Fig. 6. The bending is associated with a reduction of the elastic property. For each material, the variation can be approximated by a linear regression. Contrary to zone A, the slopes of the approximations vary noticeably from one foam to the other. They vary between 3 and 9 and are presented in Table III. The important variation of the value of the Young's modulus, even for small compression, highlights the influence of a pre-strain of the sample. Initially, for no compression, the solid matrix of the foam is isotropic at the macroscopic scale and consequently statistically isotropic at the microscopic scale. During the "bending regime," the cells collapse nonuniformly along the thickness of the sample. This behavior of the microstructure corresponds statistically to a decrease of the macroscopical Young's modulus. Consequently the variation of the Young's modulus is induced by the pre-strain, and the mechanical behavior of the foam must be modeled by an anisotropic tensor. Nevertheless, in the proposed approach, both static compression and acoustic excitation are along the thickness of the sample, and the approximation of a monodimensional model is still valid.

D. Bending regime (Zone B) for the acoustical bench

The acoustical bench is now considered in this subsection. Results for the melamine reference foam and for the bending regime are presented. Figure 7 presents the absorption coefficient for several degrees of compression (0, 0.033, 0.067, 0.1, and 0.133). The mechanical so called resonance, associated with the quarter wavelength of the fast Biot wave, is characterized by a loss of the absorption due to the reduction of viscous effect in the fluid. This resonance frequency shifts in the low frequencies with the increase of compression. This is in accordance with the results presented in Fig. 16 of Ref. 15. The resonance frequency is determined for each degree of compression. The Young's modulus associated with the different cases can then be calculated through relation (7).

Figure 8 presents the normalized elastic modulus for the acoustical bench. Two samples of the melamine foam, to ensure the validity of results, are tested with the acoustical

TABLE III. Material classifictaion in function of the compression slope on Zone B.

Foam	1	2	3	4	5	6
Slope	−9.08	−3	−5.08	−4.36	−3.65	−5.54

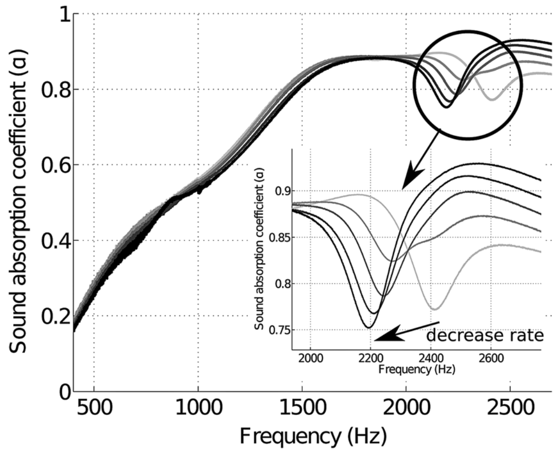

FIG. 7. Acoustic absorption measurement: variation of quarter wavelength resonance.

bench; the results are close. Similar to the comments on the mechanical bench, the variation of mechanical property can be approximated by a linear regression. For sake of comparison, the results obtained with the mechanical bench are also presented. A difference occurs in the slopes of both measurements. This is due to the Poisson effect, which is more important in the acoustical setup. When compressed in the longitudinal dimension, the material tends to expand in the radial direction. As it is limited by the tube, the Poisson effect is confined and induces a rigidification of the structure. Hence, two opposite effects occur during the compression in the tube: The bending of beams and the confinement of the structure, which tends to increase the Young's modulus. The consequence is that the reduction of the Young's modulus observed for the acoustical bench is lower than the one of the mechanical bench. Indeed, in the rigidimeter procedure, the structure is free at its lateral surface. Thereby, the sample is not confined, and the Poisson effect is negligible.

Nevertheless, it is a well-accepted idea that the compression of the sample can increase the rigidity of the material due to the Poisson effect and the confinement. Our results indicate that the bending effect can counterbalance the stiffening due to confinement. In our results, a global reduction of the Young's modulus is observed. It means that the bending effect is more important than the Poisson's.

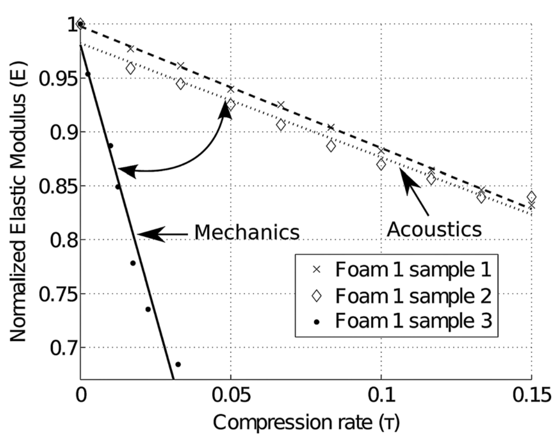

FIG. 8. Normalized elastic modulus for the acoustical bench: comparison between the two experimental setups.

V. CONCLUSION

The variation of the Young's modulus of compressed acoustic foams has been investigated for several foams with two types of experiments: A quasi-static ridigimeter and an absorption measurement bench. Four zones were identified. They can be interpreted by micro-structural considerations. It has been observed that weak compressions are associated with two different regimes: Compression and bending. As the compression regime corresponds to very small degree of compressions, it is associated with a reduction of thickness lower than 2 mm for our 4 cm thick sample. In practical application, it is obvious that the material is compressed in the bending regime when it is inserted, for example, between two panels.

A comparison between the quasi-static and the acoustic measurements has been made and presents the same tendencies. Both results indicate that the variation of the Young's modulus can satisfactorily be approached by an affine function in the bending regime. This also indicates, even for samples of the same family of material, that the slope of the affine function takes very different values. In addition, the lateral conditions can greatly modify these values for the same material.

It is interesting for practical applications to measure several (3 or 4) degrees of compressions to determine the influence of the bending regime in mechanical characterization of acoustic foams.

ACKNOWLEDGEMENT

The authors would like to thank A. Podkowskiy and A. Zhdanov for their useful contribution during the experiments

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