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CHARACTERIZATION OF THE ELASTIC PROPERTIES OF CORRUGATED FOAMS

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ABSTRACT

Corrugated foams can be used in packaging to protect goods in a parcel during transport. Corrugations are also found in vibration decoupling materials used underneath heavy load building screeds. The shape of the bumps has a strong impact on the compressional and bending stiffnesses. The main advantage of this type of material is to control the bending and compression behaviors independently. The bending depends on the stiffness of the homogeneous part of the material while the compression is mainly driven by the shape of the bumps. The goal of this work is to study the influence of the geometry of the corrugation on the elastic properties of the material. For this, measurements have been performed on foams with different corrugation profiles by using a uni-axial and quasi-static compression test. The measured properties correspond to the apparent stiffness and the damping of the material as functions of the compression rate applied on the sample. These measurements are compared with a simple analytical model which considers the bumps as springs in series. These results help understanding the performance and draw guidelines for the design of efficient noise mitigation solutions under a prescribed compression rate.

Keywords: *corrugated foams, compression behavior, elastic properties*

1. INTRODUCTION

Corrugated foams are defined by wavy surface textures, created through the cutting process (see Fig. 1). In addition to their common use in packaging, these materials are also used in the building industry for sound insulation in screeds or for pipes [1].

The wording "corrugated" can also be applied to other materials, such as metal or plastic, that have been formed into a wavy pattern. Corrugated shapes can be used on stiffer materials to control bending and compression independently depending on the size of the bumps created by the corrugation. This is useful in a building application for modifying the breathing frequency of the transmission loss of a double-walled partition system without affecting the critical frequency.

This work focuses on the characterization of the elastic properties of corrugated foams in compression. The elastic parameters such as the stiffness and apparent Young's modulus of corrugated foams have been measured using a uni-axial compression setup. Then, a simple analytical model is proposed to predict the response of the foams in compression.

2. EXPERIMENTAL SETUP

The method is based on the measurement of a Frequency Response Function (FRF) of sample bonded onto a vibrating support (see Fig. 2). A cylindrical sample is placed on a shaker and a prescribed static compression rate is applied by pressing the sample against an infinitely rigid frame. The acceleration of the shaker and the force applied on the sample are measured by means of an accelerometer and a force sensor, respectively. Then, the analysis of the FRF allows to determine the structural properties of the material, which are the apparent stiffness, the apparent Young's modulus and the damping loss factor.

The apparent Young's modulus is linked to the intrinsic Young's modulus of the material by a factor which

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Figure 1. Studied corrugated foams. Top: smooth corrugations. Bottom: strong corrugations.

depends on the shape factor [1] of the sample and on the Poisson's ratio of the material [2]. In this paper, the intrinsic Young's modulus of the plain materials has been estimated from the apparent one by assuming a Poisson's ratio equal to 0.4 which corresponds to the standard value of plain foam materials.

3. ANALYTICAL MODELLING OF THE CORRUGATION

The model assumes that the corrugated material can be represented by two cylinders of different diameters on top of each other (see Fig. 3).

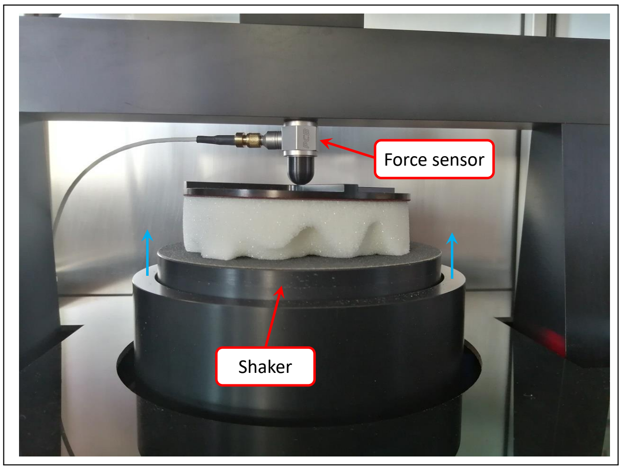

Figure 2. Experimental setup.

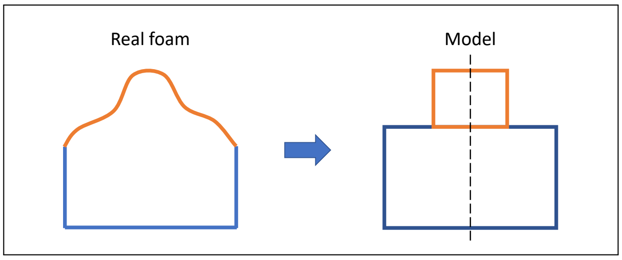

Figure 3. Scheme of the cross sectional view of the corrugation.

The first cylinder, of large diameter, represents the base while the second one, of smaller diameter, represents the bumps created by the corrugation. Each cylinder is modelled as a spring defined by its stiffness K. As the stiffnesses are not identical, their deformations differ and thus their compression rate. The intrinsic modulus of each cylinder is thus modified. This non linear problem has to be solved iteratively. For each compression rate, the force applied to the structure is calculated by means of the total stiffness estimated at the previous compression rate and the total displacement δ at the current compression rate:

$$F_i = K_{i-1}\delta_i, \tag{1}$$

where i corresponds to the i-th iteration. Then, the actual thickness h of each cylinder α is calculated from the applied force and their stiffness at the previous compression rate:

$$h_i^\alpha = h_{i-1}^\alpha - F_i/K_{i-1}^\alpha. \tag{2}$$

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[1] The shape factor is defined as the ratio between the sample volume and its free lateral surfaces.

The model is initialized by considering h_0^α as the initial thickness of each cylinder.

The stiffness of each cylinder is then calculated at the current compression rate from its thickness and surface, and the intrinsic Young's modulus measured on a plain sample:

$$K_i^\alpha = E_{\text{int}}(cr = cr^\alpha) S^\alpha / h_i^\alpha. \tag{3}$$

The value of the Young's modulus is selected at a compression rate which corresponds to the compression rate of each cylinder.

Finally the total stiffness of the material is calculated at the current compression rate by adding the stiffness of the spring in series:

$$K_i = 1 / \sum_\alpha 1/K_i^\alpha \tag{4}$$

4. RESULTS

Fig. 4 compares the apparent Young's modulus measured on materials without corrugations and with smooth and strong corrugations (see Fig. 1). All three materials were made from the same base foam.

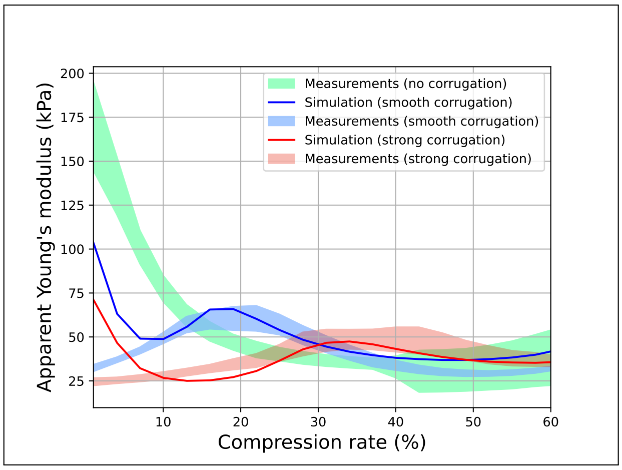

Figure 4. Measured and simulated apparent Young's modulus of materials with smooth, strong and without corrugations.

We can see that the Young's modulus of the foam without corrugation decreases up to 40% of compression due to the buckling of the ligaments. At higher compression rates, the ligaments are entirely folded. We begin to stress on the material that constitutes these ligaments, which slowly increases the Young's modulus.

For the materials with corrugation, the curves have a bell-shape. As a first step, the bumps created by the corrugation are compressed since they are less stiff than the base part of the material. The Young's modulus increases until reaching a maximum (around 17% of compression for smooth corrugations and 35% for strong corrugations) when the bumps are almost totally compressed. The value of this maximum is different in each case and depends on the thickness of the remaining plain part. When the bumps are almost totally compressed, the base part starts compressing. The behaviour of the material becomes similar to the one of a plain material and the Young's modulus decreases as observed previously.

The apparent Young's modulus estimated with the analytical model seems consistent with the measurements. Some deviations are visible below 10% of compression. In this range of compression, only the bumps are compressed. The results of the model are overestimated due to the assumption that the bumps have an identical intrinsic Young's modulus as a plain material.

5. CONCLUSION

In conclusion, this paper analyses the compression behaviour of the elastic properties of corrugated foams. These properties have been obtained by measurements using a uni-axial compression method. A simple model which compares the material as two cylinders on top of each other has been established. The assumptions made by the model are sufficient to correctly capture the behaviour of the material in compression. The results show that the Young's modulus of the foam without corrugation decreases due to the buckling of the ligaments while for materials with corrugation, the curves have a bell-shape. The maximum value and the position in compression of this maximum depend on the size of the corrugation.

Future work could focus on improving the accuracy of the model and investigating the effect of other corrugation designs on the material behavior.

6. REFERENCES

[1] P. Tommasini and D. Tardio. Investigation into the air borne flanking sound transmission paths of waste water pipes and acoustic lagging In *Proc. of Acoustics 2012 - Fremantle* , Fremantle, Australia, 2012.

[2] C. Langlois, R. Panneton and N. Atalla. Polynomial relations for quasi-static mechanical characterization

of isotropic poroelastic materials In J. Acoust. Soc. Am. , 110:3032–3040, 2001.