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1pSA6. Improving the sound absorbing efficiency of closed-cell foams using shock waves

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Producing closed-cell foams is generally cheaper and simpler than open-cell foams. However, the acoustic efficiency of closed-cell foam materials is poor because it is very difficult for the acoustic waves to penetrate the material. A method to remove the membranes closing the cell pores (known as reticulations) and thus to improve the acoustic behavior of closed-cell foam material is presented. The method is based on the propagation of shock waves inside the foam aggregate where both the shock wave generator and the foam are in air at room conditions. Various shock treatments have been carried out on a Polyurethane foams and the following conclusions were drawn: (1) the reticulation rate increases and thus the airflow resistivity decreases while increasing the amplitude of the shock treatment; (2) the softness of the foam increases; (3) the process is reliable and repeatable and (4) the obtained acoustic performance is comparable to classical thermal reticulation.

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INTRODUCTION

The acoustic efficiency of closed-cell foams is poor compared to open-cell foams since it is very difficult for the acoustic waves to penetrate inside the material. A method to improve the acoustic behavior of closed-cell foam is to remove the membranes closing the cell pores; known as “foam reticulation”. The two main reticulation methods commonly used in the foam industry are thermal and chemical. The thermal method involves placing a bun of foam in a very large vessel filled with an explosive gas mixture. The gas is ignited and a controlled flame front passes through the foam, melting the window membranes. The chemical method involves running the foam through a caustic bath which dissolves the window membranes.

A novel reticulation method is presented in this paper. It is based on the propagation of shock waves in the foam microstructure: the shock wave (i.e., a high amplitude pressure wave) propagates in the microstructure and destroys the thin membranes closing the cells. The shock wave based reticulation method offers a number of new and important capabilities, as compared to the aforementioned commercially available systems: (1) the reticulation rate of the treated foam can be tuned depending on the shock strength, (2) the treatment can be varied upon the foam surface to create “acoustic patches” or transverse flow resistance variation effects, (3) it can be applied rapidly and easily in an assembly line, (4) it does not involve chemical products and/or immersion of the foam in a fluid or hot gas, and thus does not require drying or cooling the foam after treatment and (5) it is inexpensive.

This paper presents an experimental validation of the proposed reticulation method. Five different Polyurethane foams are reticulated using shock waves. The reticulation efficiency is evaluated from airflow resistivity and sound absorption measurements and compared to the thermal reticulation method.

METHOD AND EXPERIMENTAL SETUP

The foam reticulated in this work has a flexible frame. The impact of a shock wave on the foam involves (i) the propagation of elastic and plastic waves within the porous frame and (ii) a large frame deformation^{1,2}. This shock-foam interaction is used in this work to rupture the membranes closing the foam cells³.

A shock tube is used to generate controlled shock waves in a gaseous medium. Both the shock tube and the foam are in the same gaseous environment, i.e., air at room conditions. One common type of shock tube uses two tube sections and is illustrated in Fig. 1. The so-called driver or primary section of the shock tube is filled with a high pressure gas from an external supply. A great amount of energy is thus accumulated in this primary tube. The primary tube is separated from a secondary tube via an impermeable partition, such as a breakable membrane or a high speed valve; this secondary tube is filled with low pressure gas (preferentially air at room conditions). When the partition is suddenly removed, a shock wave is generated and propagates in the secondary tube toward the material face placed at the output. A precise control of the driver pressure at rupture is required to generate shock waves of desired strength. It was found that the major controlling parameter of the shock treatment is the Mach number (M_s) of the shock wave. The amplitude of the shock (i.e., of the treatment) increases with the Mach number. Several parameters can be modified to control the Mach number of the shock wave. They are: gas pressures, gas species, lengths of the high pressure and low pressure sections of the tube, filling time of the high pressure gas and temperature. In this work, only the gas pressure in the high pressure section is varied to change the Mach number and thus the treatment's strength. The gas used in the high pressure section is Nitrogen. The pressure is varied from 60 psi to 300 psi to give a Mach number ranging between 1.35 and 1.85. The inner diameter of the shock tube is 1.5 inches. All samples presented in this paper are treated on both sides with similar shock amplitude in order to get samples as homogeneous as possible along the thickness. All samples are 1 inch-thick.

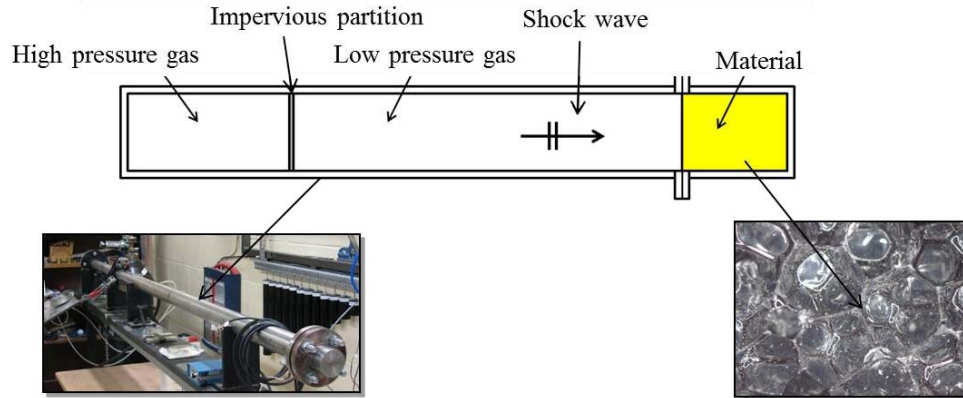


FIGURE 1. Experimental setup; Shock tube.

TEST MATERIALS

Five different Polyurethane foams are treated using the proposed reticulation method. Their cell density varies from 8ppi to 80ppi. The cell density in ppi (ppi=pore per inch) is provided by the Woodbridge group. The reticulation rates⁴ (i.e., open pore content) have not been estimated but it is expected to be less than 10%. Figure 2 shows a micrograph of an untreated polyurethane foam (foam N1). It is clear that most of the pores are closed by the thin membranes. The main objective of this work is to increase the reticulation rate; thus improving the cells interconnectivity. The materials are characterized by their airflow resistivity and their sound absorption coefficient. The airflow resistivity of the materials is used as a measure of the treatment efficiency. Indeed, this characteristic parameter decreases when the amount of broken membranes increases⁴. This parameter is measured according to standard ISO-9053:1991(E)⁵. Airflow resistivity measurements are given in TABLE 1. The sound absorption coefficient is also presented. It is measured according to standard ISO-10534-2⁶ using a 1.5 in diameter impedance tube. It is important to note that the sound absorption coefficient is not a characteristic of the treatment efficiency. Indeed, the sound absorbing efficiency can be decreased by the reticulation process if the airflow resistivity of the untreated sample is already close to its optimum value⁷ (note that the sample thickness is constant in this work and equal to 1 inch).

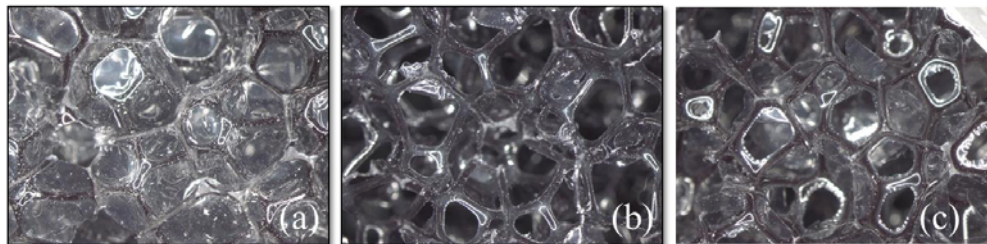


FIGURE 2. Micrographs of the polyurethane foam N1; (a) before reticulation, (b) after thermal reticulation; (c) after “shock reticulation”.

RESULTS

The influence of the shock strength is first investigated on foam N5. The foam is subjected to a shock treatment with increasing strength from $M_s=1.35$ to $M_s=1.85$. Each sample is treated on both sides with identical shock wave strengths. The thickness of the material slightly decreases when the shock strength increases, as shown in Fig. 3(a). Indeed, the porous frame is highly compressed when the shock wave hits the porous surface and the gas momentum is transferred to the foam mass¹. The foam compression is thus sufficiently important to reach a plastic deformation. This thickness decrease comes with a foam density increase since the mass of the sample is not modified by the

shock treatment (see Fig. 3(b)). Figure 3(c) shows that the airflow resistivity logically decreases with increasing shock strength; i.e., the amount of broken membranes increases. The original resistivity is divided by 6.3 for $M_s=1.85$. However, a plateau seems to be reached for $M_s > 1.7$. As the airflow decreases, the low frequency sound absorption decreases (below 1 kHz) but the medium and high frequency sound absorption is greatly improved (see figure 3(b)). The proposed method can this be used to tune the airflow resistivity of the material. This cannot be done using the thermal reticulation.

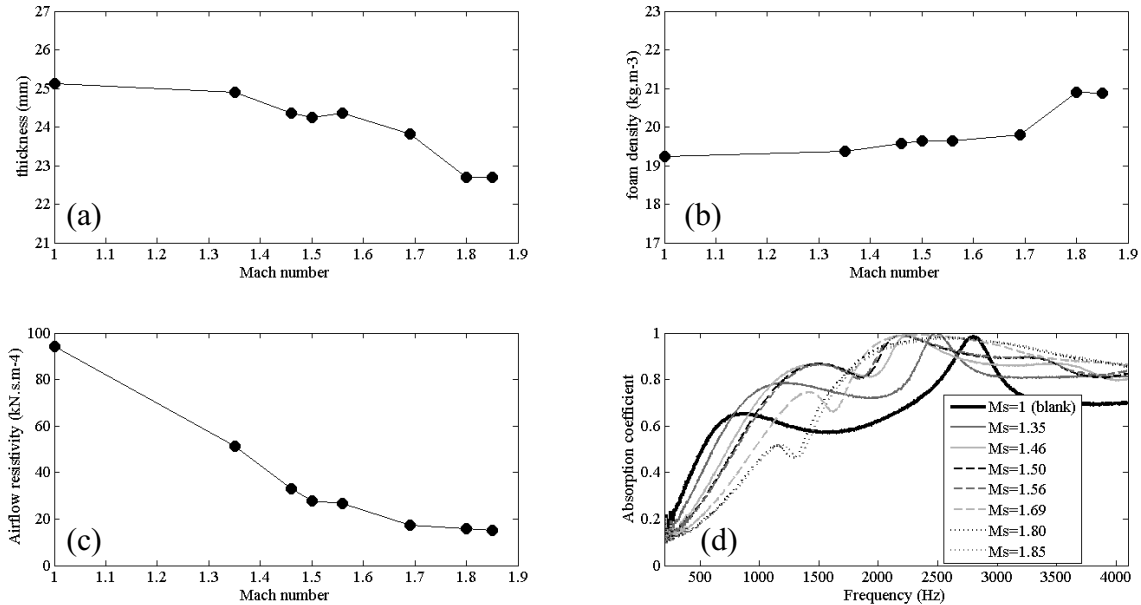


FIGURE 3. Influence of the shock treatment strength on material N5: (a) sample thickness; (b) foam density; (c) airflow resistivity; (d) sound absorption coefficient.

Figure 2 presents several micrographs taken on foam N1 before and after being reticulated. Figure 2(b) shows that the thermal reticulation melts all the membranes. The burnt membranes then stick around the struts. During the shock reticulation, both faces of the sample are impacted by a shock wave with a Mach number of 1.8. The value of 1.8 is chosen since it gives the optimum treatment for material N5 (note that the optimum treatment depends on the tested material). Fig. 2(c) shows that the membranes are punctured and may stay attached to the pores. Both reticulation methods greatly decrease the airflow resistivity of the foams as shown in TABLE 1 for the 5 foams N1-N5. The thermal reticulation is slightly more efficient but both methods provide materials with airflow resistivity in the same order of magnitude. However, note that the shock reticulation applied to these foams ($M_s=1.80$) has not been optimized.

TABLE 1. Airflow resistivity (in $N.s.m^{-4}$) of 5 Polyurethane foams before and after treatment. The shock treatment is performed on both sides of the samples with a Mach number of 1.8.

Material	No treatment	Thermal reticulation	Shock reticulation
N1	30 000	273	530
N2	25 000	173	376
N3	13 000	2 840	5 370
N4	144 500	6 818	14 200
N5	94 373	-	15983

CONCLUSIONS

The present method allows for quickly reticulating closed-cell or partially closed-cell foams, so as to enhance their filtering and acoustic properties. It is based on the propagation of a shock wave within the porous frame. The method is applied to various polyurethane foams. It is shown that (i) the shock wave ruptures the membranes and (ii) the reticulation efficiency can be controlled by the shock wave strength. Moreover, the efficiency of the proposed reticulation method is found comparable to the classical thermal method.

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