Silicone foams for sound absorption: on the link between elaboration parameters and acoustic performances

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Summary

The aim of this study is the investigation of the link between the elaboration process, the microstructure and the acoustic behavior of silicone foams. These ones are obtained using a two-component silicone: Part A is the polymer and Part B the curing agent. When components are thoroughly mixed, the product will expands and cures to a foamed elastomer at room temperature. Different parameters were varied such as the ratio of A/B, the addition of a thinning agent (Silicone oil) and the increase of the curing temperature, in the aim of understanding the influence of each parameter in the foam's absorption efficiency. The microstructure of foams is analyzed using SEM and the acoustic absorption properties are measured in an impedance tube. Two non-acoustical properties are also investigated, namely the porosity Φ and the flow resistivity σ, both measured on a specific bench. Tests results show that the surface quality (obtained using water jet cutting) of samples is critical for the correct measurement of foams characteristics in impedance tube for ab-sorption but also for SEM and non-acoustical properties. It is observed that the pore cell size and inter-connected porosity of the silicone foam has a great impact on the acoustical properties. Significant enhancements of the absorption properties could be obtained in the low frequency band by adding a high quantity of agent B and increasing the amount of interconnected porous cell. An improvement in absorption is observed in the higher frequency range when a thinning agent is added to the mixture. High temperature tends to deteriorate the sample's quality by forming air cavities. **PACS no. 43.55.Ev**

1. Introduction

Noise pollution and its effects on human wellbeing, wildlife and economy is a growing concern [1]. Nowadays, many researches are focused on the reduction of vibrations and noise, in order to improve comfort in transportation, environment and buildings constructions [2, 3]. Several kinds of porous materials are studied: open cells polymer foams, natural or mineral fibrous materials among others.

Large difference in acoustic behavior can be observed when using these materials, because of the complicated adjustment of the microstructure geometry. It should be noted that these materials exhibit poor acoustic performances at low frequencies [4].

The importance of the structure and pore size distribution for the acoustic performances (absorption and transmission) and vibration damping has been pointed in different studies. Polyurethane (PU) is one of the most used and studied porous foam. PU with open cells is considered to be a good sound absorber and vibration control [5, 6].

Acoustic materials used in noise reduction are designed to absorb sound energy. The sound absorbing coefficient (often noted α) of a material

describes its sound absorbing properties. This coefficient varies from 0 (total reflection) to 1 (total reflection) [7, 8].
The knowledge of porous foam cells morphology is a key point to estimate and optimize the acoustic behavior of the foam. For instance, Zhang et al. [6] investigated the influence of the design parameters: pore size, open porosity on the sound absorption performance of PU material. A micro-macro approach would allow to understand the link between production process and acoustic absorption performances [9, 10].
Despite the advantages exhibited by polyurethane foam (cheap and lightness), this material has several disadvantages. Polyurethane is polluting in its composition, its production and inability to be recycled and a short duration of use. That's why, the use of other materials having better qualities than polyurethane should be explored.
The objective of this paper is to investigate how the elaboration parameters affect the microstructure (pore cell size, open porosity) on the absorption performance of the silicone foam. First, different parameters (components ratio, curing agent, curing temperature) were varied and different samples were synthesized. A link between the elaboration process and microstructure was observed. The results pointed out the relationship between the acoustical absorption coefficient and the microstructure. In addition, two non-acoustical properties (porosity and flow resistivity) were studied.

2. Materials and methods

1.1. Materials

1.1.1. Presentation of material

This work is focused on the silicone foam named BLUESIL RT FOAM 3240 A and B (BLUESTAR Silicones, France). This material is supposed to be used in different applications, among which production of printing rollers, production of orthopedic pieces or insulation of noise and heat.
The elaboration of this foam represents some advantages, such as easy curing, or hardness 40 in Shore 00. Moreover the material expands without employing ozone depleting CFCs or other related blowing agents.
The acoustical behaviour of this material was studied in order to check the influence of different elaboration parameters on its physical properties and acoustical performances.

1.1.2. Synthesis of silicone foam

BLUESIL RT FOAM 3240 A&B is two component silicone foam which cures at room temperature by an addition cure reaction (Figure 1). When the A and B liquid components are thoroughly mixed in 1:1 ratio, the product will expand and cure to a foamed elastomer at room temperature (Figure 2).

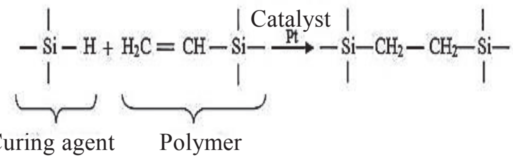


Figure 1: Chemical reaction for silicone foam elaboration

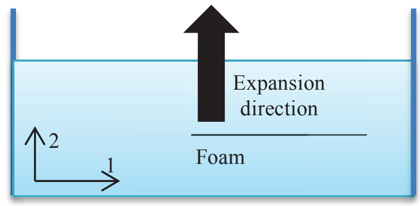


Figure 2: Expansion direction of foams

1.2. Experimental protocol

Different silicone foams are obtained by the variation of three parameters:

- A/B ratio;
- Addition of a thinning agent;
- Curing temperature.

The goal is to compare the influence of each one on the microstructure and sound absorption performance of these foams.
Moreover, different samples diameters were realized: 29mm, 44.5mm and 100mm.

1.2.1. A/B ratio

According to the technical datasheet, it is recommended to use a ratio A/B=1. The respective amount of the components A and B were varied to prepare samples having different properties compared to the reference (50% A and 50% B). Table 1 lists the elaborated samples.

Table 1: Obtained silicone foam varying A/B ratio

sample	*% A*	*% B*
Ref	50	50
30 A	30	70
70 A	70	30

1.2.2. Thinning agent

« Bluesil oil 47V» is a polydimethylsiloxane oil. It is constituted of linear molecular chains of varying lengths whose groups comprise altering silicon and oxygen atoms (the Si-O-Si siloxane bond). This oil is used as thinning agent for RTV's and silicone sealants, and anti-blotting products for photocopying machine. In our study, amounts of 5% or 25% of oil in the foam were used.

Table 2: Oil variation for obtained samples

Sample	*% A*	*% B*	*Oil (% in total masse of A+B)*
5H	50	50	5
25H	50	50	25

1.2.3. Curing temperature

The silicone foam 3240 polymerizes at room temperature. However, the variation of temperature was investigated to understand its influence on the microstructure and the acoustical behavior (Table 3).

Table 3: Curing temperature variation

sample	*% A*	*% B*	*Temperature (°C)*	*Oil (% in A+B)*
ref	50	50	25	0
40T	50	50	40	0

1.3. Measurement methods

Understanding the link between the microstructure of a material and its macroscopic properties is of great interest to predict its functional properties and then its optimization. Different parameters have been varied during the process elaboration in order to analyze the microstructure and then the acoustic behavior. The foams were aged at room temperature (22°C-25°C) for 24 h, before being cut using water jet.

1.3.1. SEM analysis

The average diameter and distribution of pores were determined with SEM. Samples were mounted on metal sample stubs with adhesive tapes, and sputter-coated with carbon or/and gold. The image analysis was performed with ImageJ software. The mean cell size and the totally/partially opened pore size were then obtained by fitting to a normal distribution.

1.3.2. Non acoustic properties

Two non-acoustic properties were studied: static flow resistivity and open porosity. The air flow resistivity is an important physical characteristic of a porous material. It describes the viscous interaction between the air and the material. The static flow resistivity σ of our samples was studied using the static airflow resistivity meter; which is specifically designed to obtain reliable measurements. The system is based on the direct method described in the ASTM C 522 (Figure 3).

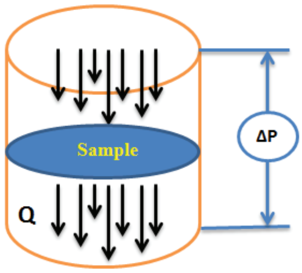


Figure 3: Flow resistivity

The open porosity Φ is defined as the fraction of volume that is occupied by the fluid in the interconnected porous network. Non-interconnected voids trapped in the solid phase are not part of the open porosity (closed porosity). The bulk density ρ is the vacuum density of the porous aggregate. The porosity meter is a system based on the pressure/mass isothermal method which allows measuring the mass of the test sample filled by gas at different pressures. From the perfect gas law, the volume of the solid phase is obtained; which allow to determinate the bulk density and open porosity of the material. Argon gas was used. Accuracy of the method increases with the bulk volume of sample and the density of the used gas. Measurements were conducted at Roberval laboratory, UTC, FR.

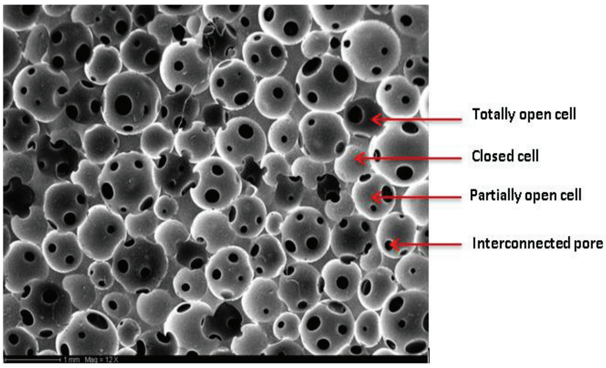


Figure 4: SEM image of the silicone foam sample

1.3.3. Absorption coefficient

The sound absorption coefficient was obtained by using a two-microphone impedance tube from Bruel & Kjær. The test was performed according to the standard procedure detailed in ATSM E1050-10. The absorption coefficient was measured using cylindrical foam pieces (specimens), 29 mm diameter and 20 mm thick, over the frequency range of 10-5000 Hz. The incident sound was normal to the surface of the foam rise direction. Each of the tests was repeated several times to obtain consistent and representative results.

2. Results and discussion

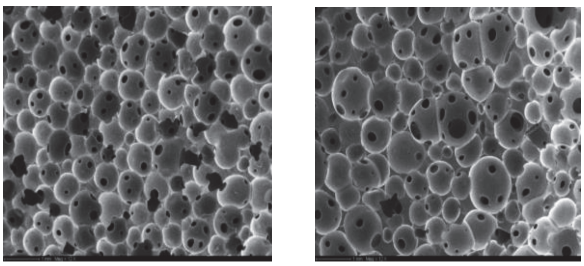
2.1. Selections of specimens

The tests show that the surface quality of the sample (Figure 5) is an important factor for a correct measurement of the foam characteristics (impedance tube for absorption, SEM and non-acoustical properties). Specimens with surface defects were ignored and not characterized.

Figure 5: Measured specimens

2.2. Cell/pore morphologies and size distribution

The acoustic behavior of silicone foam is governed by the microstructure of the different samples. Figure 6 shows the different types of pores and cells, which give a different acoustic behavior to each sample. The white parts correspond to the pore shape whereas the dark part is related to the interconnected pore and open cells. Number, size and type of pores are important factors for the sound absorption mechanism in these materials.



a) 30%A b) 70%A

Figure 6: SEM images, samples 30%A/70%B (left); 70%A/30%B (right), curing at room temperature

Figure 7 illustrates the microstructure properties of the measured samples. The average values of the cells size for 6 different samples are shown in figure 8 and in table 4.

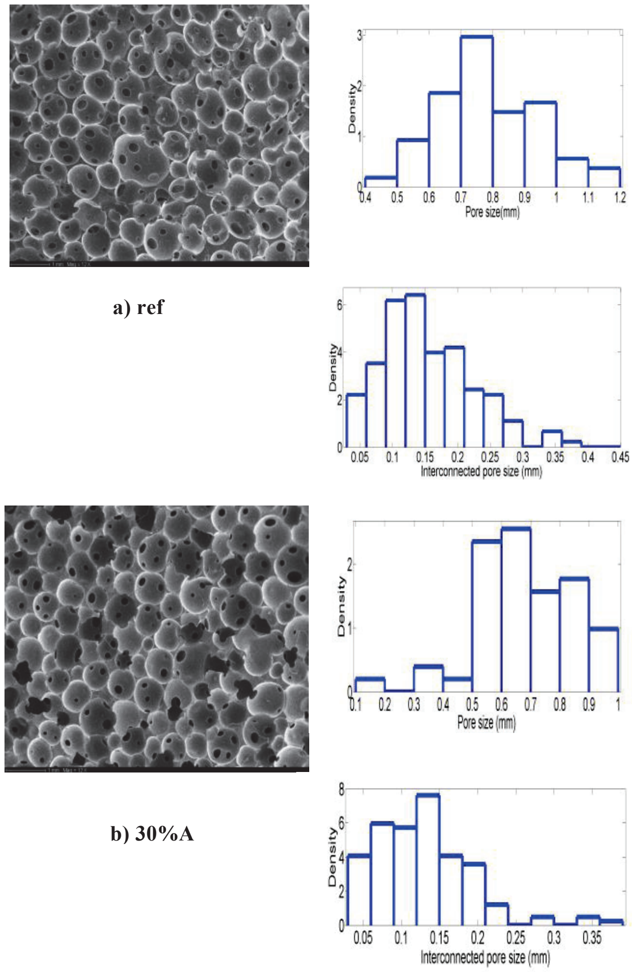


Figure 7: Cells and interconnected pores sizes for different samples

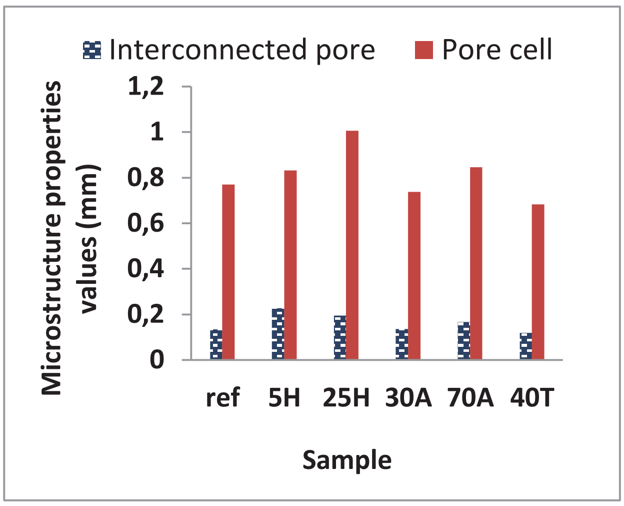


Figure 8: Cells and interconnected pores sizes for different samples

Table 1: Cell/Interconnected pore average

Sample	*Average interconnected pore size (mm)*	*Average cell size (mm)*
ref	0,13	0,77
5H	0,22	0,83
25H	0,19	1
30A	0,13	0,74
70A	0,16	0,85
40T	0,12	0,68

Regarding interconnected pores size, the average for the reference (ref) sample containing 50% of A and 50% of B is of 0.13 mm. When the curing oil is added, this average increases. 5H sample has the largest interconnected pores diameter (0.22 mm). The gap between the two samples 5H and 25H is about 13% and of 70% when compared to the reference sample. The addition of the oil contributes to the increase in size of the cell. No real effect is observed for the other components. Increasing the ratio of the B component seems to have no effect, and increasing the A component gives a moderate effect. The curing temperature (40T) doesn't seem to have a significant contribution. The largest cell diameter of 1mm is observed for 25H sample. Adding curing oil increases the pore size. The oil slows the curing process and allows to the cells swell and then reticulates. The same note is observed when the part B (curing agent) is less than the part A (70A). The cell diameter is about 0.85 mm. The Part A and B ratio influences rather the number and nature of the pores.
The high curing temperature (40T) tends to decrease the pore size. When the temperature is increased; the curing process is happened more quickly compared to the cell swelling, which explains the small cell size. In comparison, the reference pore cell size curing in room temperature is 11% bigger than for 40T. The ratio of each type of cell is investigated and represented in table 5.

Table 5: Microstructure properties ration of the different silicone foams

Sample	*ref*	*30A*	*70A*	*25H*
Partially open cell (%)	84	51	75	77
Totally open cell (%)	10	22	10	14
Closed cell (%)	6	27	14	9

We notice, for all samples, a large ratio of partially open cells, a small amount of completely open cell and a low ratio of closed cell (Figure 7).
The reference sample (Figure 7(a)) contains 84% of partially open cells, which is the largest ratio of the tested samples. Sample 30A (Figure 7(b)) has the lowest amount of partially open cells, the largest ratio of open cells and closed cells. Compared to the reference, 25H (Table 5) has less partially open cells but more totally open and closed cells. The 70A and 25H have almost the same ratio of partially open cells. These measurements data depend on the distinction of the open/closed pores that is not always obvious, but this approach can help to differentiate the different samples. Microstructure properties comparison could be used in the absorption acoustic behavior analysis.

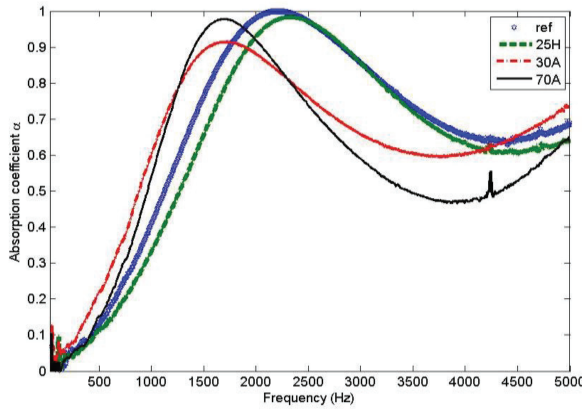


Figure 9: Influence of pore cell size on sound absorption coefficient

2.3. Acoustical behavior

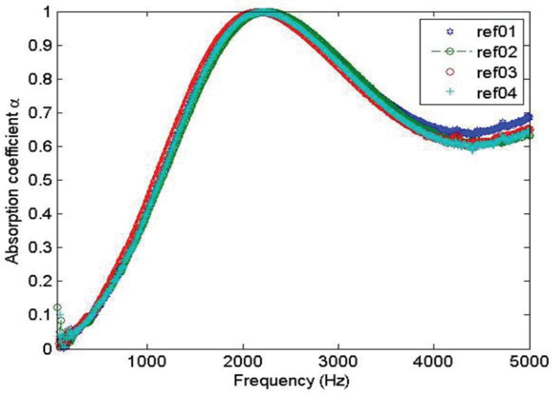
Acoustic absorption performances of 29 mm diameter specimen were studied.
The absorption coefficient of four types of samples is presented in figure 9. All the curves have a well identified maximum. It is at a lower frequency for samples 30A and 70A, around 1700 Hz, but the 30 A curve is smoother. The "ref" and 25H samples have their maxima between 2200 Hz and 2400 Hz. As a consequence, the sample 30A is the most efficient in the low frequency domain whereas the 25H is the less efficient in this domain.
The difference observed for the absorption coefficient can be caused by the difference in the microstructures that are influenced by the elaboration process.

2.4. Process repeatability

The goal of this section is to show if the elaboration process is repeatable. Acoustic behaviors of "reference" silicone foams have been investigated.
Figure 10 represents the absorption coefficient of four "supposed identical" samples "ref" (29 mm

diameter and 20 mm thick) made separately with the same proportion of Part A and B and curing at room temperature. The four curves are held together, which illustrate the good repeatability of the elaboration process.

Figure 10: Influence of the repeatability of the elaboration process in absorption coefficient



2.5. Non acoustical properties

Table 6 shows values of the two non-acoustical properties, air flow resistivity and porosity, for four 100 mm diameter samples.

Table 6: Resistivity and porosity of different composition silicone foam sample

Sample	*σ [N.s.m^{-4}]*	*Φ*
ref	11010	0.80
70A	23085	0.93
30A	81902	0.91
25H	11258	0.86

Values obtained for the "ref" and "25H" foams are typical of low air resistivity polymeric foams. The values for 70A are twice and are even higher for the 30A that can be said to be a high resistive material. This sample has the largest pore size and the smallest size of interconnections between the pores. This explains that the 30 A is the more absorbing material in the low frequency range.

Porosities values given in table 6 are quite high (>0.8). They correspond to the typical sound absorbing materials and confirm the ability of the silicone foams to absorb sound efficiently.

3. Conclusions

For this study, the elaboration process, the pore size morphology, the sound absorption performances and two of non-acoustical properties of silicone foams were studied.

The pore size depends clearly on the elaboration process and on the composition. The cell size changed towards a larger cell size from 1 to 0.76 mm in diameter.

The sound absorption coefficient of the silicone foam can be improved in low frequencies by reducing the part of A component and be improved for high frequencies by adding oil.

Further investigation to link the process elaboration, microstructure (pore morphology) and the acoustic performance could help to better understand the behavior of the silicone foam and then lead to better configuration for absorbing systems.

Acknowledgement

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