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Comparison of the acoustic behaviour of porous materials in compressed and uncompressed conditions

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Abstract

Conventional methods to evaluate the absorption coefficient of materials use either a large reverberation room or wave guides such as standing-wave tubes or impedance tubes. These last methods have recently been extended so that other material properties such as airflow resistivity can also be evaluated using the same tubes. An advantage of the impedance tubes is that they can also be used to measure the acoustical and non-acoustical properties when the materials are under compression. The current study investigates the differences between two-microphone systems and three-microphone systems, and assess both the absorption coefficient and the flow resistivity of porous materials such as rock wool and fibreglass in both compressed and uncompressed conditions. Finally, the results of the study are discussed.

Keywords: sound absorption, flow resistivity, porous materials, impedance tube, compressed materials**.**

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1 Introduction

Porous fibrous materials such as rock wool and fiberglass are usually used for thermal insulation purposes as well as passive sound absorbers in wall sections or in HVAC systems ducts [1].The porous materials, in situ, may be compressed, either due to high loads or while trying to fit into obstructions or while wrapping HVAC pipes. And hence, many construction guidelines such as that by Oak Ridge National Laboratory and the US Department of Energy, discuss the problems of insulation layers being compressed [2,3]. Similar to the R-value reduction, the sound absorption coefficient of the porous material is also supposed to decrease under compression. However, the effect of compression on the acoustical properties of porous materials has not been fully investigated, and only a few studies are available [4-6].

Castagnède et al. compared uncompressed and uniformly compressed polyester fibrous material used in automotive industry [4,5]. The authors found that, the absorption coefficient of a compressed sample decreased due to a "thickness effect". The compression caused the decrease of air volume in the interstices of the material, and although fibres do not change their volume, their arrangements does change, so that the apparent volume of the whole material reduced. They also found that compression of the porous layer affected other properties such as porosity, characteristic length, tortuosity and flow resistivity. In fact, the accumulation of the fibres corresponded to an increment of the resistivity and tortuosity, and to a decrease of the porosity and the characteristics length.

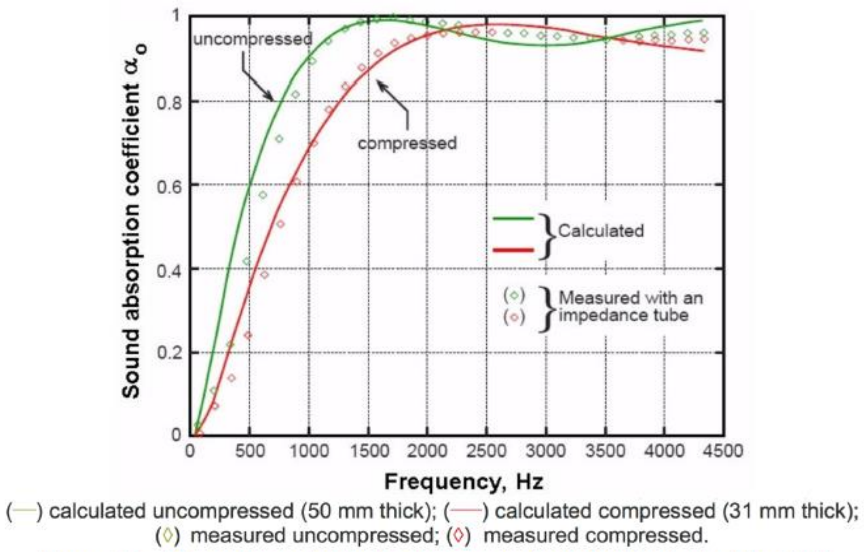


Figure 1: The effect of compression on sound absorption coefficient (Source Reference 6).

Iannace et al. showed that the non-uniform compression of a 50 mm thick polyester fiber to a 31 mm sample resulted in a clear decrease in the absorption coefficient below 1500 Hz as shown in Figure 1 [6].

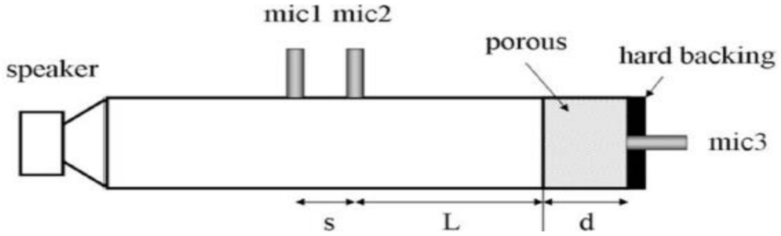
The aim of the current paper is to discuss the effects of compression on the absorption coefficient and flow resistivity of two porous fibrous material, fiberglass and rock wool. The details are described below.

2 Methodology

Sound absorption coefficient at normal incidence was measured following the procedure described in ISO Standard 10534-2 [8]. This method allows the measurement of acoustic parameters by using small samples that are easy to assemble and disassemble in Kundt's tubes. Two properties, the absorption coefficient and the airflow resistivity, were evaluated in this study. The flow resistivity is the pressure drop across a sample when it is exposed to a steady laminar airflow, and it can be measured by numerous means [9], among which researchers have recently proposed the use of modified impedance tubes.

The impedance tube is an easy and fast way to measure direct (i.e., sound absorption coefficient, sound transmission loss, effective density and effective bulk modulus) and indirect (i.e., static airflow resistivity, tortuosity, viscous and thermal characteristic lengths) acoustic properties of a material [10-12]. On the other hand, some of the limits of using the impedance tube for acoustic measurements are sample cutting, positioning, and fitting inside the tube. In addition, the method may be affected by sample resonance, and low or high frequency variability. As said, the impedance tubes can also be used to find non-acoustic parameters. Doutres et al. outlined a straightforward application to determine the non-acoustic properties of a sound absorbing porous material using an indirect method based on a three-microphone impedance tube, as shown in Fig.2a [13]. Alternatively, Tao et al. proposed a method for the evaluation of the static air-flow resistivity without modifying the tube or changing the sensor location but positioning the sample at a distance from the rigid end as shown in Fig.2b [14].

a)



b)

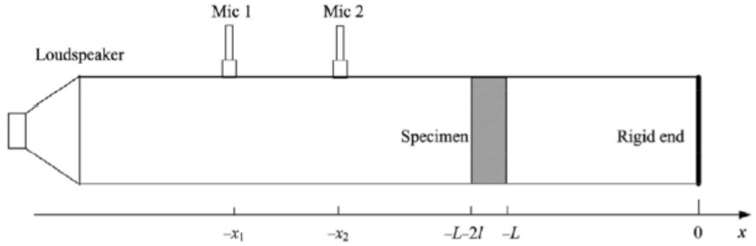


Figure 2: Sketches of two impedance tubes for the determination of the airflow resistivity.

In order to cover a broader frequency range, two Kundt's tubes, shown in Figure 3, were used in this study:

- A tube with a circular cross section with internal diameter of 10 cm (corresponding to an upper frequency limit of 2000 Hz), a length of 56 cm, and mounted ¼'' microphones, placed at a distance of 5 cm, was used for measurements above 200 Hz;
- A tube with a square cross section with sides of 30 cm, and mounted ¼'' microphones, was used to cover the lower frequency from 50 Hz to 200 Hz.

The complex wavenumber of the sample of known thickness was determined from the impedance tube measurements. The surface impedance z_s and the absorption coefficient α, were then calculated from the following expressions:

$$\alpha = 1 - |R|^2 \qquad (1)$$

$$R = \frac{Z_s - \rho_0 c}{Z_s + \rho_0 c} \qquad (2)$$

$$z_s = -j z_c \cot(k_c d) \qquad (3)$$

where R is the sound pressure reflection coefficient, z_c is the characteristic impedance ($\rho_0 c$), k_c is the complex wavenumber and d is the thickness of the sample (m). To limit the effects due to the irregularities in the samples, different measurements were performed for each sample, and the measurements reported in the section 4 are average results.

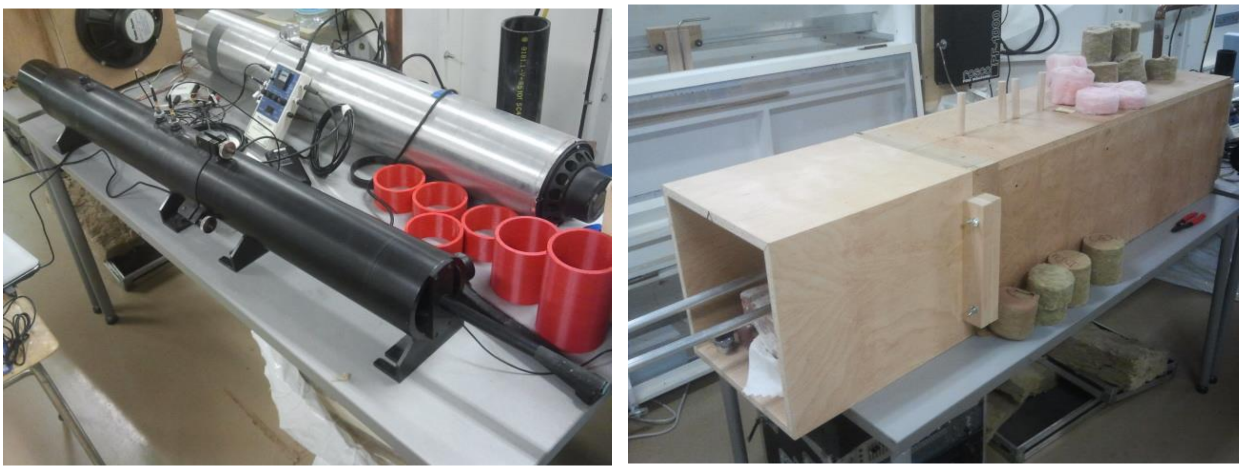


Figure 3: Circular and square impedance tubes used for the measurements.

3 Tested materials

As previously reported, different rock wool and fiber glass materials as well as some open-cell foam were considered in the study. Table 1 reports some of the main properties of the assessed materials. To control the size and shape, the samples were cut using a band saw and a compass cutter to the desired dimensions and thickness. The circular samples were prepared by piercing a hole through the centre to act as a holder. The process aimed to maintain uniform shape between all the samples.

Table 1: List of porous materials investigated in this paper.

Material	Sample	Density, kg/m^3	Compression rate
Fiberglass	Duct liner	10	1.60
Rockwool	AFB DD2 R24	45 65-100 32	1.33 1.33 1.33 and 1.22

Castagnède et al. showed that the flow resistivity of a porous material is proportional to the 1D compression rate [4]. This can be defined as the ratio between the original thickness, and the compressed thickness. According to Castagnède et al. [4], the compression rate can hence be used to calculate the compressed flow resistivity, as a product of the uncompressed air flow resistivity for the compression rate.

The compression for the larger square samples was accomplished by pushing the rigid end plunger into the sample holder. For the denser samples such as DD2 and AFB, blocks of bricks were built up at the back of the plunger to help maintain the hold of the compressive state. Similarly, the compression of the circular samples was achieved by wrapping the samples using nylon stockings. The stockings were knotted at the end to keep the enclosed samples compressed. Several variations of the compression were tested and compared to find the best orientation. The nylon was believed to act as an acoustically transparent membrane without causing significant resonance effects. However, uniaxial compression may not have been properly achieved due to the difficulty of uniformly compressing the samples; in fact, the action of knotting the end of the stocking resulted inadvertently in some bi-axial compression.

Literature has often shown that the cutting process likely causes slight deformation in the sample that directly affects the leakages [15,16]. As the sample is compressed, additional edge constraint was supposed to occur with effects on the results.

4 Results

The comparison between two-microphone method and the three-microphone method is presented first. Since the two-microphone method evaluates only the static air-flow resistivity, Table 2 highlights only the resistivity values for the rockwool DD2 sample as well as for two different foams of different density.

Table 2: Airflow Resistivity of porous materials.

Material	Sample	Condition	Two mic method, MKS Rayls/m	Three mic method, MKS Rayls/m
Rockwool	DD2	Uncompressed	12,000	18000
Foam	Foam 2	Uncompressed	3,500	4,000
	Foam 3	Uncompressed	4,000	4,500

It can been seen that the three microphone method evaluated a higher value of the static air-flow resistivity for rockwool. However, the two methods proposed in [13] and [14] provided comparable values for the open-cell foam material used for the investigation. It must be pointed, however, that the fibrous materials did not fit tightly in the impedance tubes used for the study.

Figures from 4 to 7 show the results of the sound absorption measurements for the different materials. Compression was found to affect the absorption. In fact, as the samples were compressed, the absorption coefficient decreased especially at low frequency.

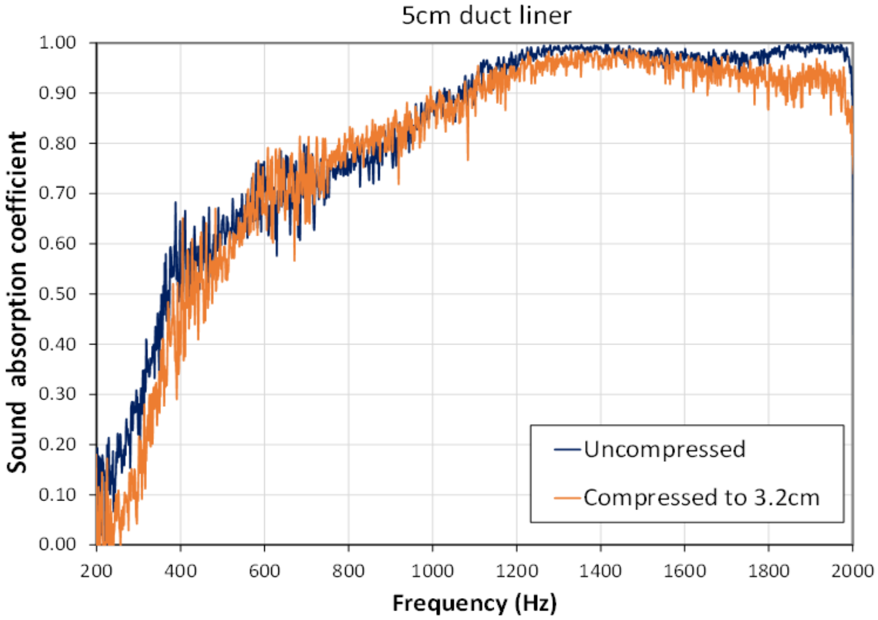


Figure 4: Sound absorption for 5 cm sample of duct liner (also compressed to 3.2cm).

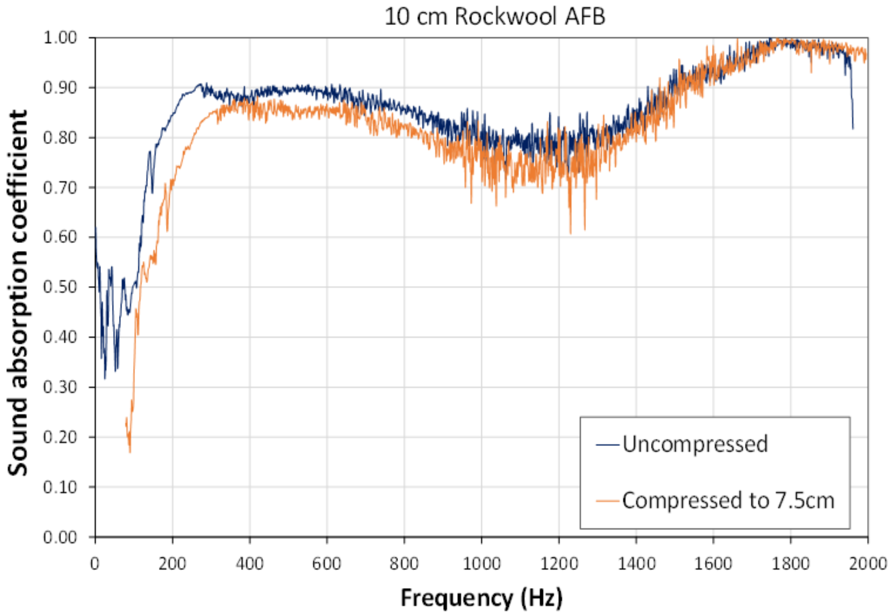


Figure 5: Sound absorption for 10 cm sample of rockwool AFB (also compressed to 7.5cm).

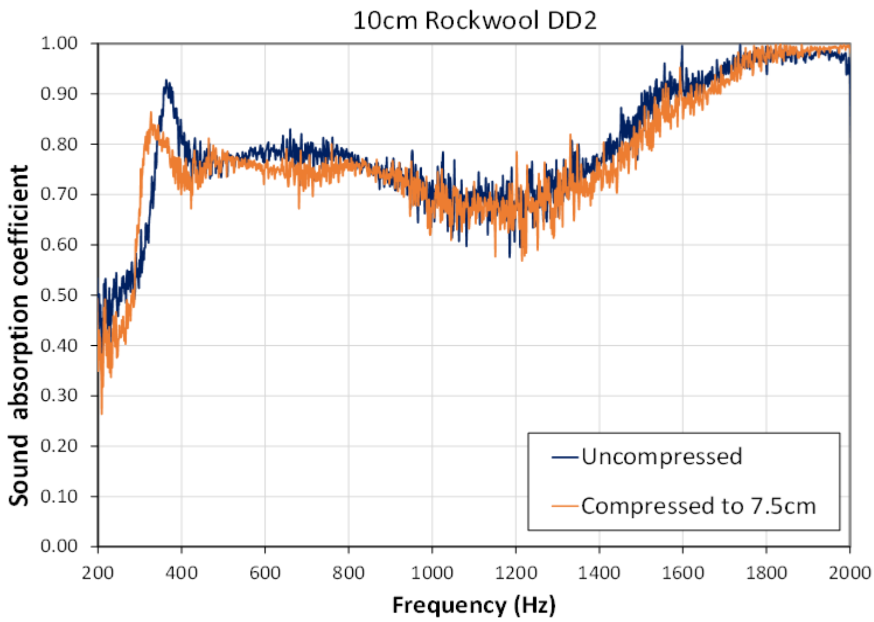


Figure 6: Sound absorption for 10cm sample of rockwool DD2 (also compressed to 7.5cm).

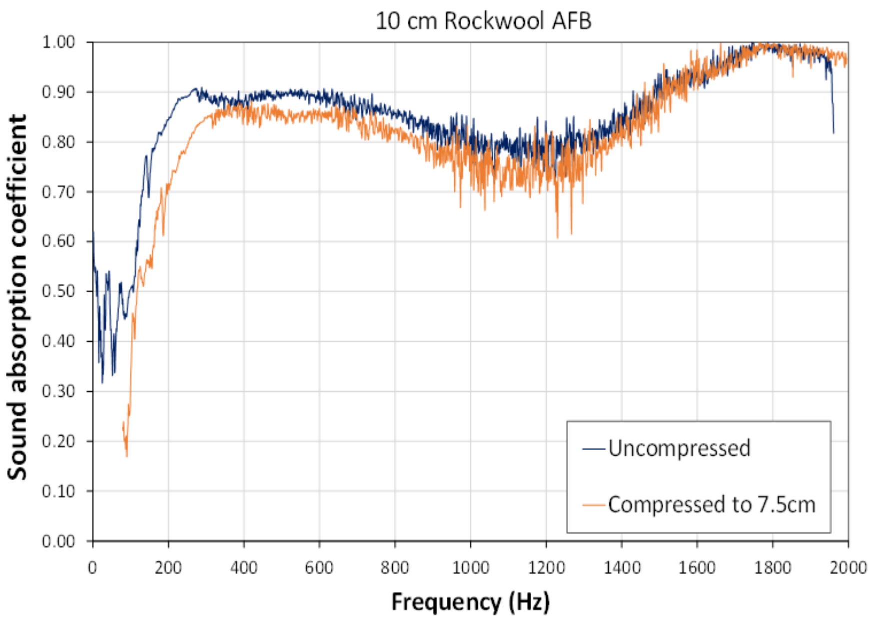


Figure 7: Sound absorption for 10cm sample of rockwool R24 (also compressed to 7.5cm).

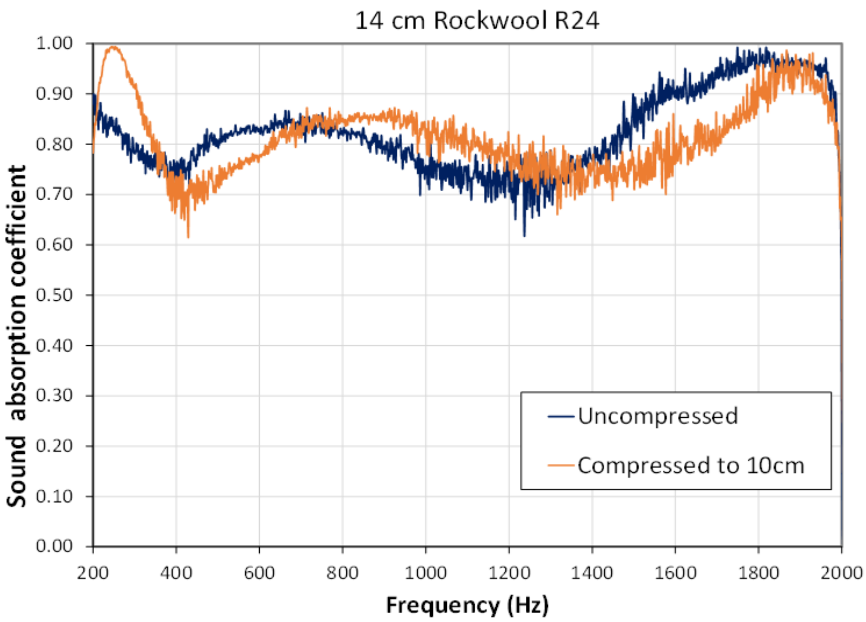


Figure 8: Sound absorption for 14cm sample of rockwool R24 (also compressed to 10cm).

Table 3: Sound absorption results in one third octave bands.

Freque-ncy, Hz	Rock wool AFB		Rock wool R24 (10→37.5)		Rock wool R24 (14→10)		Rock wool DD2		Foam Duct liner	
	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed	Compressed	Uncompressed	Compressed
200	0.78	0.71	0.49	0.60	0.86	0.89	0.46	0.41	0.08	0.01
250	0.86	0.80	0.71	0.74	0.83	0.98	0.50	0.43	0.18	0.06
315	0.89	0.85	0.86	0.87	0.78	0.87	0.65	0.75	0.33	0.21
400	0.88	0.86	0.84	0.87	0.75	0.72	0.83	0.76	0.54	0.45
500	0.89	0.85	0.85	0.87	0.81	0.73	0.77	0.76	0.62	0.58
630	0.89	0.85	0.86	0.88	0.84	0.80	0.78	0.75	0.70	0.71
800	0.86	0.82	0.82	0.85	0.83	0.85	0.77	0.75	0.75	0.78
1000	0.81	0.76	0.76	0.79	0.76	0.83	0.71	0.70	0.87	0.86
1250	0.80	0.77	0.77	0.75	0.74	0.76	0.71	0.69	0.98	0.95
1600	0.91	0.92	0.93	0.87	0.88	0.78	0.90	0.86	0.97	0.95
2000	0.94	0.95	0.94	0.94	0.91	0.87	0.94	0.95	0.95	0.89

In order to compare the experimental results, an estimate of the flow resistivity of compressed and uncompressed material was compiled. It is expected that compression will result in a smaller and denser sample that, therefore, would experience a higher flow resistivity [9]. As expected, the results in Table 4 showed that the flow resistivity increased when the materials were compressed.

Table 4: Airflow Resistivity of porous materials, MKS rayls/m.

Material	Sample	Uncompressed		Compressed	
		Thickness, cm	Air-Flow Resistivity	Thickness, cm	Air-Flow Resistivity
Rockwool	AFB	10	12,000	7.5	21,000
Rockwool	DD2	10	21,000	7.5	30,000
Rockwool	R24	10	12,000	7.5	20,000
Rockwool	R24	14	12,000	10	18,000
Fiberglass	Duct-liner	5	9,000	3.2	12,000

5 Conclusions

The effect of compressing porous materials on their acoustic performance were investigated. Two impedance tubes were used in the study. Two microphone method and three microphone methods were applied in the experiment. The results showed that the two and three microphone methods provided comparable estimation of the static air-flow-resistivity values. The absorption coefficient of the porous materials was seen to reduce in certain frequency regions when the materials were compassed. The impact was not very considerable as the compression rates were not high. Similarly, the static air-flow-resistivity values of the porous materials did increase when the materials were compressed.

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