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AN EXPERIMENTAL STUDY OF THE INFLUENCE OF MOISTURE CONTENT IN ACOUSTIC ABSORPTION OF POROUS CONCRETE

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ABSTRACT
This work presents a study of the variation in the acoustic absorption characteristics of a material widely used in acoustic barriers according to the variation of the humidity and the amount of water retained inside. To analyse this behavior, an experimental monitoring of the normal incidence absorption coefficient for consolidated samples with different aggregate grain size, thickness and quantity of cement was made. Results reveal an important influence of moisture in the sound absorption of tested samples.

RESUMEN
Este trabajo presenta un estudio de la variación en las características de absorción acústica de un material ampliamente utilizado en barreras acústicas de acuerdo con la variación de la humedad y la cantidad de agua retenida en el interior. Para analizar esto, se realizó un monitoreo experimental del coeficiente de absorción de incidencia normal para muestras consolidadas con diferente tamaño de grano agregado, espesor y cantidad de cemento. Los resultados revelan una influencia importante de la humedad en la absorción del sonido de las muestras analizadas.

1. INTRODUCTION

Porous materials based on concrete are generally used as an engineering solution for the absorption of sound outdoors, for example, in acoustic barriers. However, the sound absorption provided by such materials can be influenced by atmospheric conditions, and in particular by the presence of water (due to rain). Although this is known, scarce publications exist quantifying the variation of the absorption properties in the presence of humidity. The present work aims to contribute to enhance the knowledge on this topic, and shows a study of the variation in acoustic absorption characteristics of a material used in acoustic barriers according to the variation of humidity and to the amount of water retained inside the material. In many published works, such as those by Asdrubali and Horoshenkov [1] or Zhang et al [2], the sound absorption of granular materials is addressed and characterized. The work of Yilmazer and Ozdeniz [3] is one of the few that indeed analyses the effect of moisture and how it affects the sound absorption properties in absorbing materials (perlite plates), concluding that when the plates were moisturized and especially when saturated with water, their sound absorption coefficients were significantly reduced. The authors also demonstrated that, as it is widely known, the thickness of the sample strongly influences the absorption coefficient.

The present paper introduces an experimental study in controlled conditions in order to better understand the effect of moisture content on the sound absorption of lightweight concrete with expanded clay. In this experimental study, four variables were addressed: the thickness of the samples, cement content, the grain size of the aggregate, and the content of water retained in the sample. In what follows, the results of this study are presented.

2. DESCRIPTION OF THE TESTED SAMPLES

As stated , the variables selected in this study were: the thickness of the samples, cement content, the grain size of the aggregate, and the content of water retained in the sample. The variations of the percentages of three basic components of concrete (cement, water and aggregate) are presented in the Table 1.

Table 1. Content of the different mixtures

Mixture (nº)	Cement (%)	Aggregate (%)	Water (%)
1	34.32	48.48	17.20
2	37.38	48.96	18.64
3	39.89	40.17	19.94

In the case of the aggregate component (in this case expanded clay), two different grain distributions were used, with the following commercial names: 0-2 and 2-4. The difference in grain size affects the macroscopic properties of the samples (such as tortuosity or porosity), and may possibly affect water retention. Sixteen test samples were prepared as can be seen in Table 2.

Table 2. Distribution of the grain size in the different samples for the three mixtures

	Mixture 1	Mixture 2	Mixture 3
Grain 0-2	0	4	4
Grain 2-4	4	4	0

These test samples were stored in a chamber for several days, under controlled conditions of 18ºC and 69% relative humidity in the air, without receiving direct sunlight. Although all these samples were analyzed, onlly a limited number of results will be presented here, in order to keep the compactness of this work.

3. TEST PROCEDURE

The study was carried out along 22 days, starting with completely dry samples. The first day, they were weighted dry and their absorption coefficient measured according to the method described in the standard ISO 10534-2 [4] related to the transfer function method between two microphones in an impedance tube. The spacing between microphones is 0.05 m and the diameter of the tube is approximately 0.10 m. The distance between the nearest microphone and the sample surface is 0.25 m. Signal acquisition is accomplished through a NI USB 4431 acquisition system from National Instruments; two microphones from GRAS, model 40AE, were also used. Once the test was done, the samples were filled with water until the top. After 4 hours, they were emptied, weighted and measured again. By perferoming this operation it is possbile to appreciate the amount of water retained (allowing to see what combination of cement and grain retains more water and how it affects its properties). From that day and during the referred period of 22 days, once a day, the samples were weighted, tested in the impedance tube, and then stored in a chamber where the temperature and humidity were constantly monitored, being at 19ºC, 90% relative humidity and without contact with sunlight. The last two measurements were made after leaving the test pieces drying in a stove for 1 day.

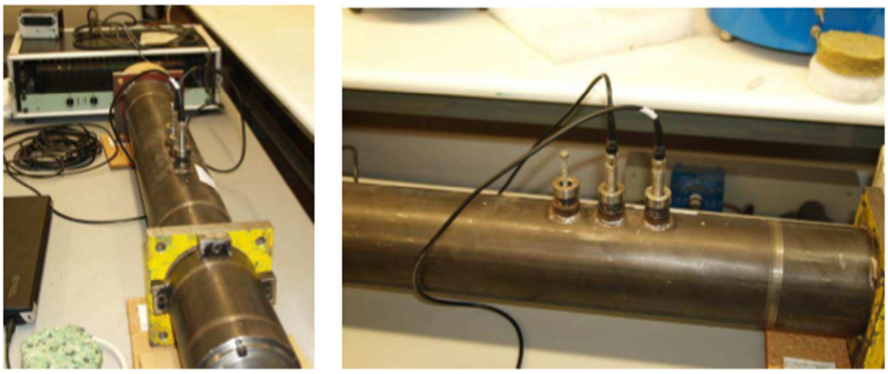


Figure 1.Experimental setup of impedance tube to evaluate the absorption coefficient

4. RESULTS

4.1 *Mixture 1*

Figure 2 illustrates the sound absorption results obtained for Mixture 1, for samples 4 cm thick; Table 3 exhibits the evolution of the weight of the samples. The curve that represents the dry samples indicates that the samples exhibit a pronounced absorption peak around 1300 Hz, reaching an absorption coefficient of almost 1. As can be seen in this figure, the behaviour of the tested samples in terms of sound absorption has some dependency on the level of water retained by the sample. If we carefully observe these graphics, in both cases the same phenomenon happens, and the curve is wider in the samples that are drier. The loss of absorption can be explained by the water that has been absorbed by the material, reducing the porosity of the sample, and thus reducing its acoustic absorption capabilities. It is also interesting to note that the curve related to the wet sample (14/5/18) seems to exhibit a somewhat different behaviour, with a slight shift of the peak to the left, and with a considerably narrower peak.

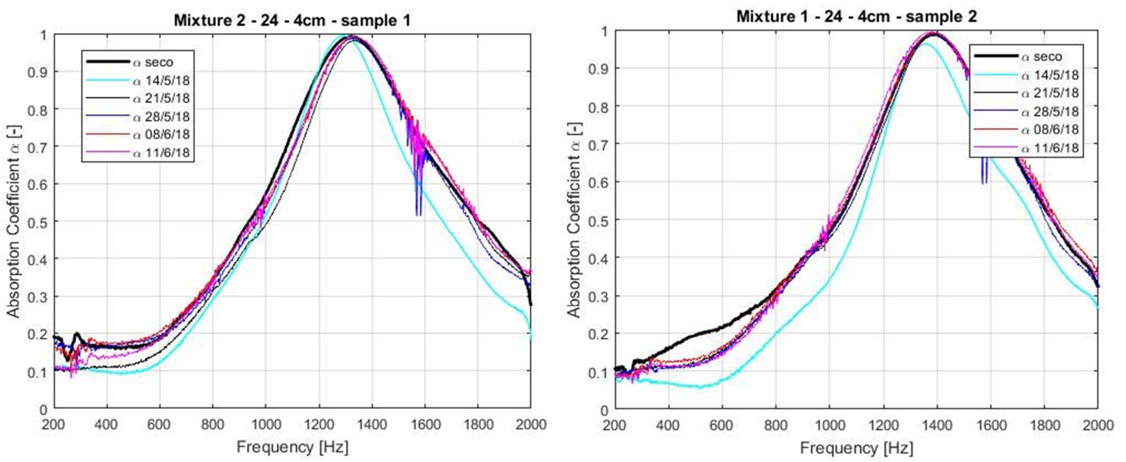


Figure 2. Graphical representation of the sound absorption of samples made with Mixture 1 and 2-4 grain size for 4cm thickness

Table 3. Weight evolution with the variation of content of water in samples of Mixture 1

	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	196,59	237,92	222,60	214,55	201,07	199,3
Sample 2 (g)	206,35	236,23	226,20	218,27	209,09	207,34

When the specimens made of Mixture 1 and with 8 cm of thickness are analysed (Figure 3 and Table 4), a strong shift of the absorption peak towards lower frequencies occurs, and a maximum value is now reached around 600 Hz. This behaviour was expected and it is in line with what is reported in the literature. The influence of moisture is not so evident as before, although a somewhat narrower curve is registered for the first day (14/5/18).

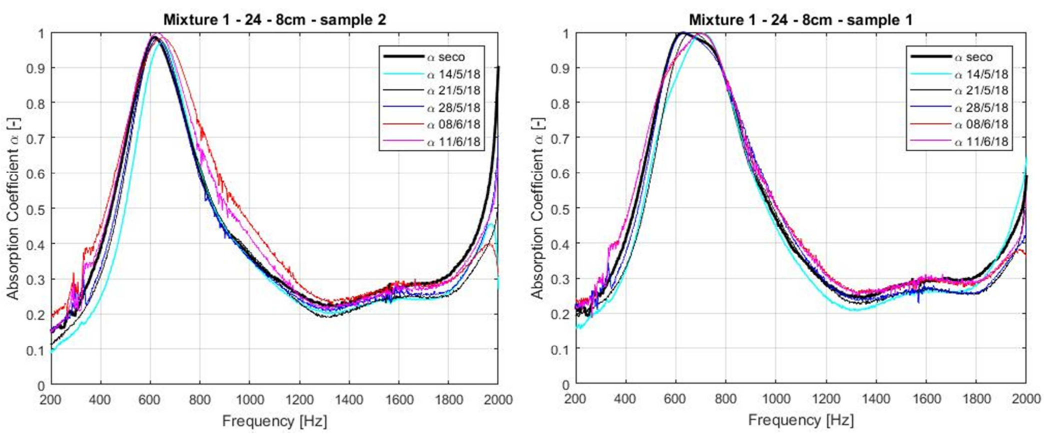


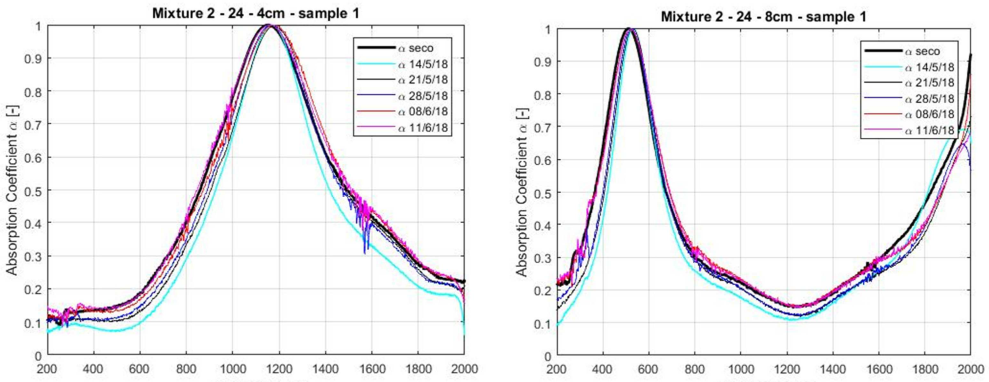
Figure 3. Graphical representation of the sound absorption of samples made with Mixture 1 and 2-4 grain size for 8cm thickness

Table 4. Weight evolution with the variation of content of water in samples of Mixture 1

	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	353,16	417,88	404,25	396,35	378,34	369,41
Sample 2 (g)	358,39	415,17	403,63	395,98	379,4	369,28

4.2 *Mixture 2*

Results obtained for Mixture 2 and for grain size 2-4 can be seen in the Figures 4a and 4b and in Tables 5 and 6, for thicknesses of 4 and 8 cm, respectivelly. When comparing with the results above (Figure 2), a quite similar behaviour can be identified, although with the peak absorption occuring at slightly lower frequencies, and with narrower bell-shaped curves being produced, which seems to be an effect of the larger cement content of the samples. As before, the saturated samples (dated 14/5/18) seem to change visibly, but the curve quickly recovers to the original sound absorption levels.



a) b)

Figure 4. Graphic representation of samples made with Mixture 2 and 2-4 grain size, for 4cm (a) and 8cm (b) thickness

Table 5. Weight evolution with the variation of content of water in samples with 4cm thickness.

	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	234,82	273,13	263,87	256,45	240,52	236,87
Sample 2 (g)	274,35	318,86	304,18	296,98	287,24	282,73

Table 6. Weight evolution with the variation of content of water in samples with 8cm thickness.

	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	412,27	480,67	468,69	461,27	442,35	433,54
Sample 2 (g)	363,86	425,53	416,04	408,88	387,56	377,48

As can be seen in the Figure 5, the variation of the grain size can change the location of the peak of absorption and make the bell-shaped curve wider. In the previous configuration (Mixture 2, grain 2-4 and thickness 4) the peak was around 1100Hz and in this sample the peak is now in 1300Hz and the bell is wider. The behaviour varies visibly from the first day after being saturated to the others days. Indeed, when the highest moisture level is registered (14/5/18), the absorption curve is significantly shifted to the left, both in the 4cm and 8cm thick samples.

However, after one week, the original levels are almost recovered. It is interesting to note that the effect of moisture seems to be intensified when smaller grain size is used.

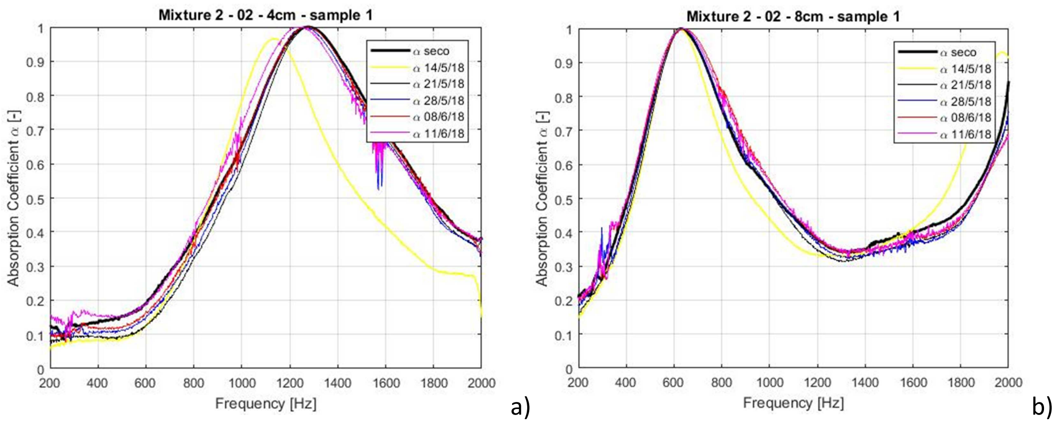


Figure 5. Graphic representation of samples made with mixture 2 and 0-2 grain size, for 4cm (a) and 8cm (b) thickness.

Table 7. Weight evolution with the variation of content of water in samples 4 cm thickness

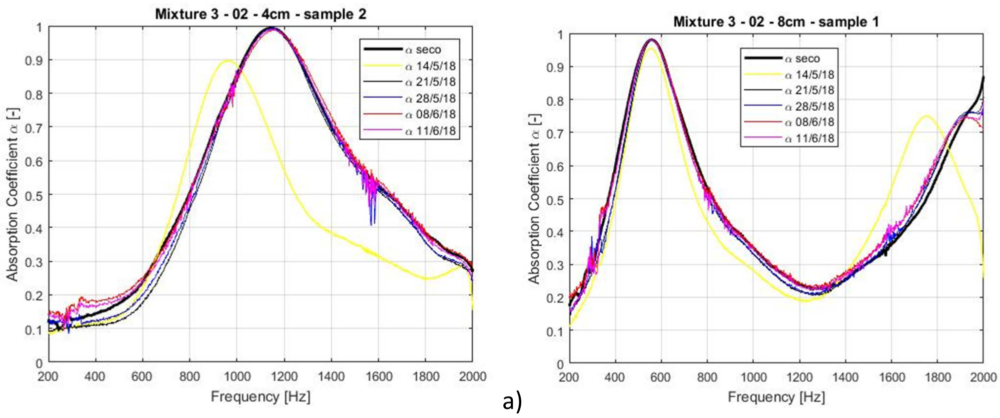
	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	240,43	288,76	279,54	270,86	250,14	243,45
Sample 2 (g)	257,02	319,11	306,5	297,2	275,04	268,31

Table 8. Weight evolution with the variation of content of water in samples 8 cm thickness

	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	418,83	504,99	492,76	484,89	460,14	446,52
Sample 2 (g)	428,52	523,87	511,29	502,75	476,87	462,78

4.3 Mixture 3

In Figures 7a and 7b results for Mixture 3 are shown, using 0-2 grains and 4cm and 8cm samples. As seen in Mixture 2, it can be observed that the presence of a high content of moisture originates quite visible changes in the absorption curve, with a decrease and shift to the left of the absorption peak. This result is very much in line with the previous ones and, once again, seems to reveal a tendency for the infleunce of moisture to be more pronounced when smaller grains are used. It is also interesting to note that, as observed for grain size 2-4, the increase in cement quantity originates narrower bell-shaped curves.



a) b)

Figure 6. Graphic representation of samples made with Mixture 3 and 0-2 grain size for 4cm and 8cm thickness

Table 8. Weight evolution with the variation of content of water in samples 4cm thickness.

	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	292,03	348,7	333,16	323,84	307,26	301,1
Sample 2 (g)	260,55	316,61	303,07	293,56	271,3	264,3

Table 9. Weight evolution with the variation of content of water in samples 8cm thickness.

	Dry	14/5/18	21/5/18	28/5/18	8/6/18	11/6/18
Sample 1 (g)	467,46	555,6	543,9	535,82	514,35	502,54
Sample 2 (g)	494,44	584,28	573,51	564,88	547,22	536,42

5. CONCLUSIONS

A set of samples made of a porous lightweight concrete, incorporating expanded clay, was produced in the context of this work, and analysed from the point of view of the sound absorption coefficient. The effect of moisture content on the sound absorption was analyzed, and some conclusions could be drawn:

1. Cement quantity influences the shape of the absorption curve of the tested specimens. As smaller quantities of cement are used, a broader absorption range seems to be obtained, for both types of grain-size used in the granular material. This is probably due to a reduction of the internal porosity of the samples;
2. As expected, the thickness of the samples plays a fundamental role in the range of absorbed frequencies. Thicker samples allow absorption at lower frequencies, although in a more limited frequency range;
3. The level of moisture of the sample is of high importance, and influences significantly the absorption of the sample. Higher moisture contents seem to lead to lower absorption and to a narrower frequency range in which the sample provides significant absorption. However, after one week of drying, the samples almost recovered their initial state. Indeed, this was the main issue to be addressed in this work, and can be of high practical importance, since in many

case the studied materials are used in outdoor applications, as for instance in traffic noise barriers, for which sound absorption is of utmost importance.

ACKNOWLEDGEMENTS

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