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RESEARCH ARTICLE

ACOUSTICAL PROPERTIES OF LIGHTWEIGHT CONCRETE FROM SCORIA

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ABSTRACT

Today much importance is given to the acoustical environment. This work investigates the acoustic properties of porous concretes made from scoria by showing the influence of physical prosperities of materials like material thickness, density, and porosity on their absorption behaviors. The high absorption achieved in some frequency bands, depending on the concrete dosage, confirmed the possibility of using lightweight structural slag and insulating materials for custom acoustic interventions. Finally, results show the good coefficient absorption capability of scoria, making them a promising alternative to traditional porous concrete solutions.

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INTRODUCTION

With the present world scenario, the noise pollution associated with the population growth and the industrial development represents a major problem for people living mostly in urban areas by inducing stressful conditions and a great deal of inconvenience. This situation underlines the need for a continuing search for new active materials known as « sound absorptive materials » which can reduce the acoustic energy of a sound wave by the phenomenon of absorption. The mechanisms involved in such absorption are precisely related to plate absorptions, radiation (Rudra, 2011), sound and structural Vibration-Radiation from sandwich beams using MPP (Sakagami, 2017). Efforts have been already made to find out sound absorptive materials which can be used in many fields such as interior lining for apartments, automotives, aircrafts, ducts, enclosures for noise equipments and insulations for appliances (Knapen *et al.*, 2003; Youn Eung Lee, 2004).

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In particular, some scientific studies have been dedicated to sustainable concrete-based materials made from natural or recycled materials for the same purpose. Various porous concretes have been therefore tested experimentally and have been found to be acoustically efficient, as exemplified by autoclaved aerated concrete enhanced by incorporation of fibrous (Mallampalli *et al.*, 2016), porous concrete with grain dispersion, shape, and size (Seracettin, 2011) or porous concrete using recycled aggregate. On the other hand, concrete of low density can be obtained by substituting classical aggregates of sand and pea gravel with artificially lighter aggregates, for instance the expanded polystyrene beads (Aman, 2016). As part of our ongoing study on the scoria-based concrete, we investigated herein its lightweight part for possible sound absorption property by conducting different acoustic assays with respect to the thickness, density and porosity of the scoria.

MATERIALS AND METHODS

Materials: The following materials were used to produce the concrete used in this research work.

The cement used in this study was of Type I (ASTM C 150) (ASTM, 2009) whose physical properties and chemical composition are shown in Table 1. Potable water was used under the provisions of ASTM C1602 and was employed to mix and cure concrete specimens as (Kucche *et al*., 2015). A special method called "powder method" was applied to ground slag samples into powder. The equipment used is a SIEMENS diffractometer using a monochromatic X-ray by CuKa radiation with a wavelength k = 1.7903 A° at a voltage of 40 kV and a current of 30 mA. Fig 7 and 8 show the exploitation of the diagrams related to the two samples. The x-ray diffractogram profiles show an overall similarity for both samples in the position of the crystallization peaks. The absence of quartz is noted among most of the minerals characterized. On the other hand, peaks of labradorite are apparent in spite of their similarity with those of andesine, making the demarcation somewhat difficult. An olivine is also detected and is attributable to ferromagnesian. The products exhibited some differences namely a notable preponderance of augite peaks for scoria in sample s1 and diffuse bands in the diffractogram of the sample s2. However, the vertices correspond to the diffraction lines of the same crystallized phases. Table 2 shows the results of chemical analyzes on these samples while Table 3 summarizes the main characteristics of the scoria samples used in this study.

It is worth mentioning that we have followed the ASTM C618 (ASTM, 2001) procedure to establish the scoria characteristics. Analyses show that all scoria samples are conducted in compliance with ASTM standard. The alkali contents presented in Table 4 are given in equivalent Na2O content which is usually used by cement manufacturers (Andreas, 2008). According to these results, the scoria from s2 are poor in alkalis although they are known to contain these chemicals. Careful verification was made by measuring the apparent and absolute density of the sample aggregate and the natural water content of the scoria. The averages of apparent density found for the S1 and S2 aggregates were 1.46 T/m^3 and 1.47 T/m^3, respectively, and 2.80 and 2.89 T/m^3 as averages of real density, respectively. The water content value was about 6% for these two samples. The dust in the scoria used is locally available and meets the classification requirements of ASTM C-117 (12). It has a density of 1.15 T/m3 and shows an average proportion between 0.4 and 0.6% of material with size greater than 75 µm. The scoria met the requirements of ASTM C-33 (13) for both the range and the average proportion of materials under 75 µm. Fig. 3 shows photographs of these two samples.

Methods

Experimental methods are needed to better understand the phenomena and mechanisms governing the behavior of fine constituents and coarse aggregates. To obtain an optimal formulation of concrete, some authors (Shehdeh *et al*., 2016; Yogesh *et al*., 2015) have studied the composition of a granular mixture and its initial "arrangement". The calculation of the quantity of materials that make up a concrete allowed us to decide whether the desired concrete is voluminous or no-fine. The mass of a 4x4x16 cm parallelepiped sample was determined using a KERN Pit 720-3A precision weighting balance. The actual volume of the scoria (Vr) aggregates is constant for the compositions categorized by the two samples. It should be noted that for the compositions c3, c4, c8, c14, c16, we have reduced the quantity of Vr to improve its effectiveness on the void ratios. Then, we have gradually increased the cement dosage to meet the vacuum ratio results. The amounts of the fines used were calculated to respect the total value of the absolute volume of the mixture, in substitution of cement. We separated the concrete compositions from the two samples to follow the influence of the scoria gap indices. The formulation related to the manufacture of materials, as specified in tables 5 and 6, was chosen according to the analyzed parameters. Different sizes of molds are used for the production of specimens according to the general objectives of the project. Prisms with heights of 10, 20, or 30 cm and a constant side length of 8.5 cm were used.

Acoustical characterization: The sound absorption coefficient has always been considered as one of the most important physical parameters needed for the evaluation of acoustical efficiency. Its determination was performed in a reverberation room by applying a 2260 Bruel and Kjaer sound level meter with a 4189 Bruel and Kjaer 1/2" microphone, and an omnidirectional sound source (4296 Bruel and Kjaer). Spatial arrangement was made for nine set of microphone located at least 1.6m away from each other. The measurements were performed following the ISO 354 procedure (Rosendahls, 2006; Kimura *et al*., 2014). Shock tests are carried out as follow: a concrete slab of rectangular section is slightly embedded in one point and excited with a small hammer of shock to induce a longitudinal vibration through the plate. The perceived sound is analyzed from the software "sound forge", whose height depends on the density of the concrete, as well as the dimensions of the plate. To evaluate the transmission of the impact sound through a concrete slab, a machine with five steel clad hammers is used in accordance with ASTM E-492 (ASTM, 1996; Wilson, 2015; Technical Bulletin, 2014). The obtained value for the sample corresponded to the Impact Insulation Class (IIC).

RESULTS AND DISCUSSION

Absorption coefficient: The measurements of sound absorption were carried out on three types of scoria noted G1, G2 and G3 from the coarse to the finest granulometries, with a density of 1720 Kg.m-3. They were made in normal incidence with samples of a thickness of 10 cm over a frequency range from 150 to 2000 Hz. Measurements were performed on the three samples to assess the reproducibility of the assay. We note from Figure 4 that the representativeness of the volume is ensured, with less than 5% variation in sound absorption between samples. In addition, particles with fine size D1 were slightly more efficient at low frequencies, and at medium frequencies, while particles with coarse and medium sizes D2 and D3 had the same behavior. Finally, Fig 5 shows that a decrease in grain size brought about a shifting of the absorption peaks to low frequencies and make overall scoria more absorbent. This effect of particle size is much more marked in the sample 2 than in sample 1. Moreover, we note in all the configurations, an excellent level of acoustic absorption with $\alpha \geq 0.3$ for frequencies higher than 300Hz. The acoustic properties of the two scoria samples were finally characterized. Given the importance of particle size as stated above, it is first necessary to ensure the accuracy of the expected results by carrying out preliminary experiments. Besides the size of the Kundt tube used for the assay, the grain size and the water content of scoria are paramount factors to be considered. The measurements of the absorption coefficients were made using the vertically held 10 cm diameter Kundt tube and the three

Table 1. Physical and chemical properties of Cement.

Chemical compound	%	Physical properties		%
SiO2	20,5	Specific gravity (g/cm3)		3,15
Al2O3	4.52	Specific surface (cm2/g)		3897
Fe2O3	2.71	Setting time initial (min)		157
CaO	63.93	Compressive strength (MPa)	1 d	10.5
MgO	2.39		3 d	21.6
K2O	1.01		7 d	28.0
SO3	3.3		28 d	42.0
Na2O	0.19	Setting time final (min)		236
LOI	0.97	Soundness (mm)		1.0

Table 2 Chemical analysis of scoria

Elements	s1	s2
SiO_2	48,70	44,63
Al_2O_3	20,12	13,04
Fe_2O_3	01,13	12,48
CaO	10,58	12,08
MgO	09,81	09,56
K_2O	01,10	01,33
SO_3	00,00	00,02
TiO_2	02,81	02,29
MnO	00,22	00,21
Na_2O	02,78	02,40
Cr_2O_3	00,10	00,11
P_2O_5	00,64	00,71
LOI	02,00	01,15
TOTAL	99,99	100,01

Table 3 Scoria used in the study

Quarry	Color	Form	State of surface	Structure	Appellation
S1	purplish-blue black	scoriaceous	Very rough	Porous	scoria
S2	brick red	Circular and compact	A bit rough	Alveolar	scoria

Table 4 Alkali content of slag

Elements	s1	s2
(Na2O +0,66K2O)%	3,506	3,278

Table 5. Composition of the concretes s1

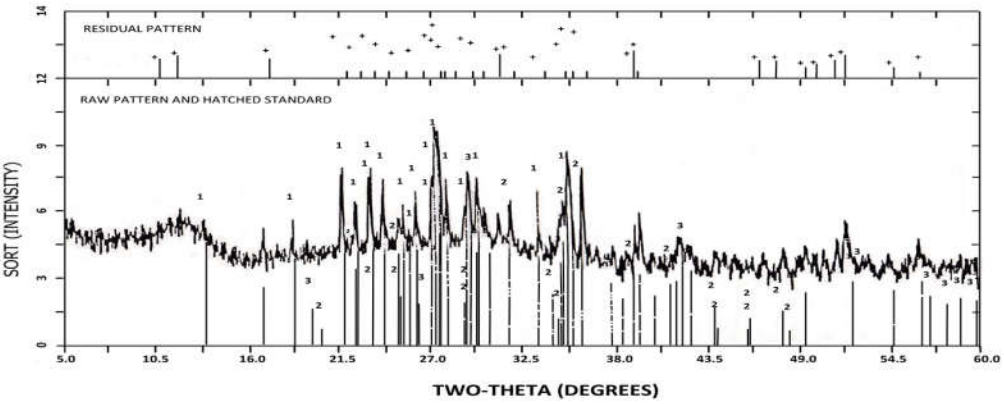
Dénomination	c.1	c.2	c3	c.4	c.5	c.6	c.7	c.8	c.9
V_c (Kg/m^3)	49	83	106	106	117	118	118	139	150
V_f (Kg/m^3)	00	00	335	335	00	81	141	232	180
V_{ab} (Kg/m^3)	275	275	89	172	275	275	275	222	275
V_r (Kg/m^3)	541	541	175	340	541	541	541	439	541
W (Kg/m^3)	168	168	168	168	168	168	168	168	168
Density (Kg/m^3)	1185	1200	1540	1750	1260	1340	1620	1720	1720

Table 6. Composition of concretes s2

Denomination	c.10	c.11	c.12	c.13	c.14	c.15	c.16	c.17	c.18
V_c (Kg/m^3)	85	115	120	120	120	122	134	140	146
V_f (Kg/m^3)	00	00	00	77	287	139	254	222	182
V_{ab} (Kg/m^3)	301	301	301	301	188	301	243	301	301
V_r (Kg/m^3)	537	537	537	537	335	537	433	537	537
W (Kg/m^3)	170	170	170	170	170	170	170	170	170
Density (Kg/m^3)	1200	1260	1265	1345	1730	1625	1715	1720	1715

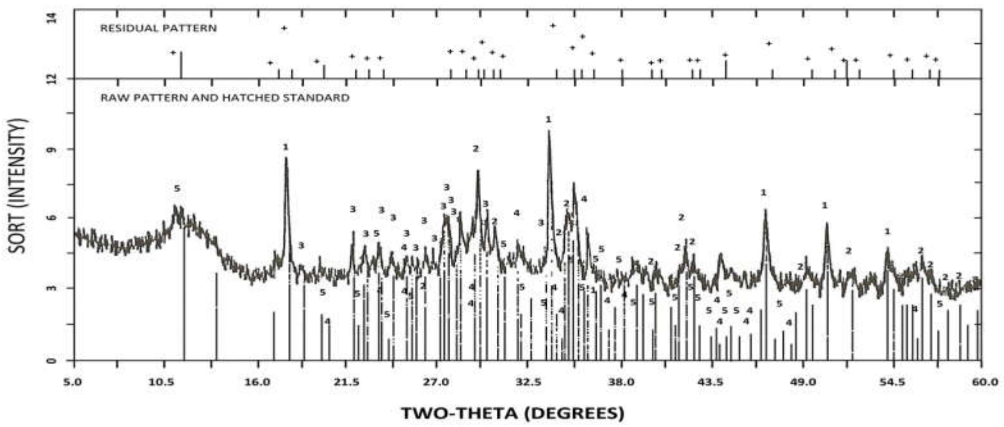
cavity-free microphones method. The thickness tested is 5 cm. The results are shown in Fig.6 and Fig.7. In general, with the increase of the frequency, except for those above 1 kHz, the absorption coefficient also increased. Furthermore, it was observed that concretes of lower dosage absorb more at lower frequencies than those of higher dosage, and inversely concretes of higher dosage absorb more at higher frequencies than those of lower dosage. Consequently, concretes of lower dosage are the most interesting in practice.

For samples c9, c18, c8, c17, c7, and c16, the magnitude of absorption is relatively stable over the entire frequency range. Lower dosages absorb sounds of medium and high frequencies, i.e. concretes c13, c5, c11, c2, c6, and c10 can be used for acoustic correction of premises. Their good absorption characteristics in the range of medium and high frequencies are also well adapted to thwart the dominant frequencies pertaining to the industrial noise. Unlike sample s2, no events were detected in the pre-peak portion of sample s1.



	FRACT	STANDARD		I/ICOR	FOM	
1	45	9.0465	(CA. NA) (SI. AL) 40	1.0	0.575	Calcic plagioclase
2	28	21.1257	(MGO. 6FEO. 4) 2SIO	1.0	0.385	Olivine (rich in iron)
3	26	24.0202	CA (MG. AL. FE) SI2O	1.2	****	pyroxen

Fig. 1. S1 X-ray diffraction analysis



	FRACT	STANDARD		I/ICOR	FOM	
1	28	4.0733	CA (OH) 2	1.4	0.703	Slaked lime
2	25	24.0202	CA (MG. AL. FE) S120	1.2	0.498	Pyroxen
3	15	9.0465	(CA. NA) (SI. AL) 40	1.0	****	Calcic plagioclase
4	13	21.1257	(MGO.6FEO. 4) 2SIO	1.0	****	Olivine (rich in iron)
5	17	14.0083	CA4AL2C09. 11H2O	1.0	****	Para-alumohydrocalcite

Fig. 2. S2 X-ray diffraction analysis

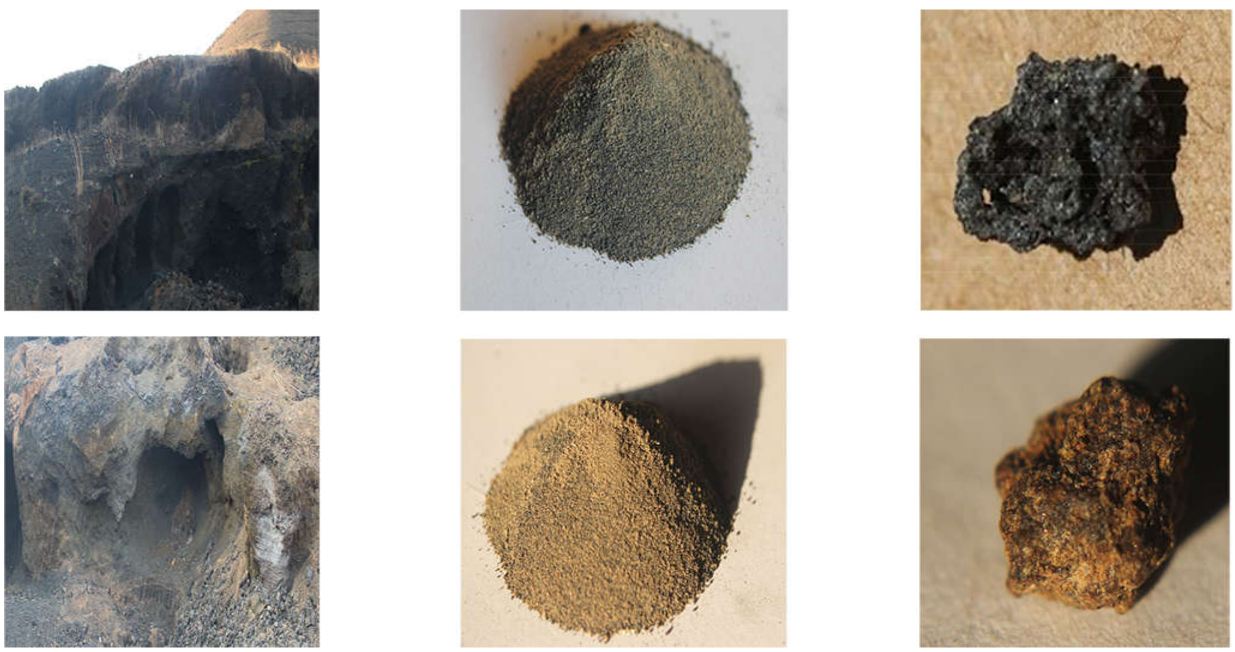


Fig. 3. S1 and S2 Scoria samples

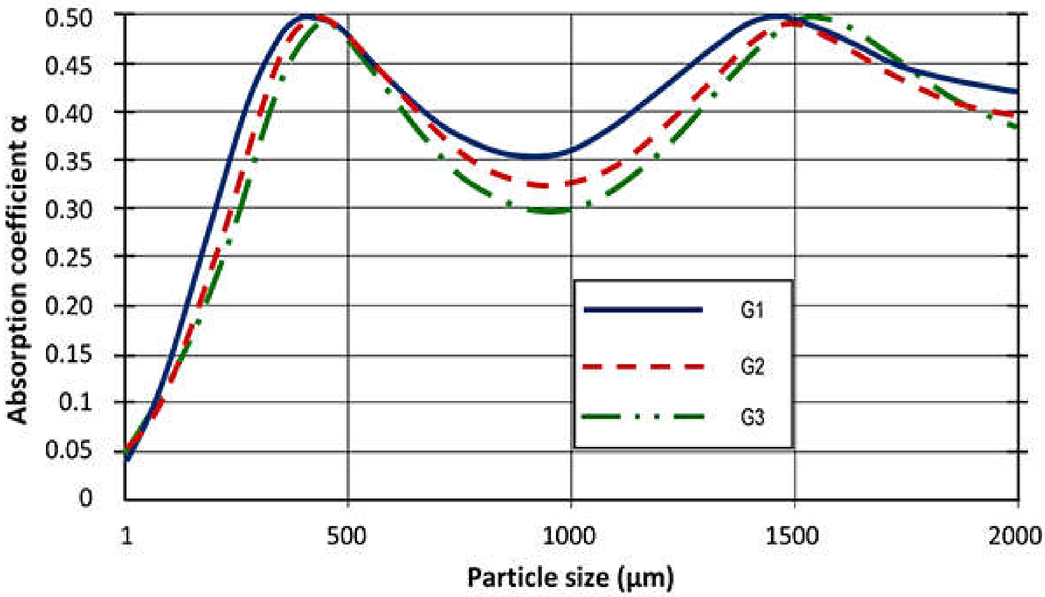


Fig. 4. S1 Effect of the particle size on the acoustic absorption

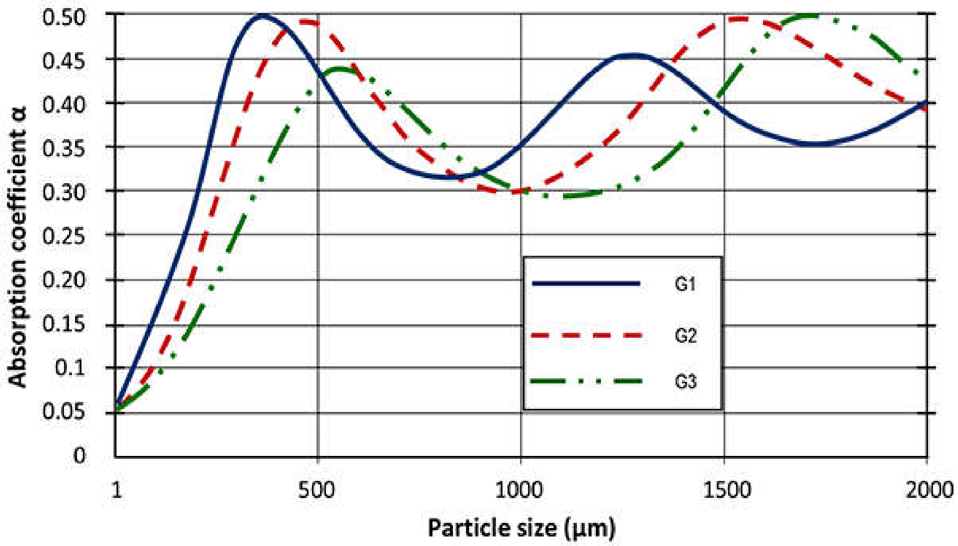


Fig. 5. S2 Effect of the particle size on the acoustic absorption

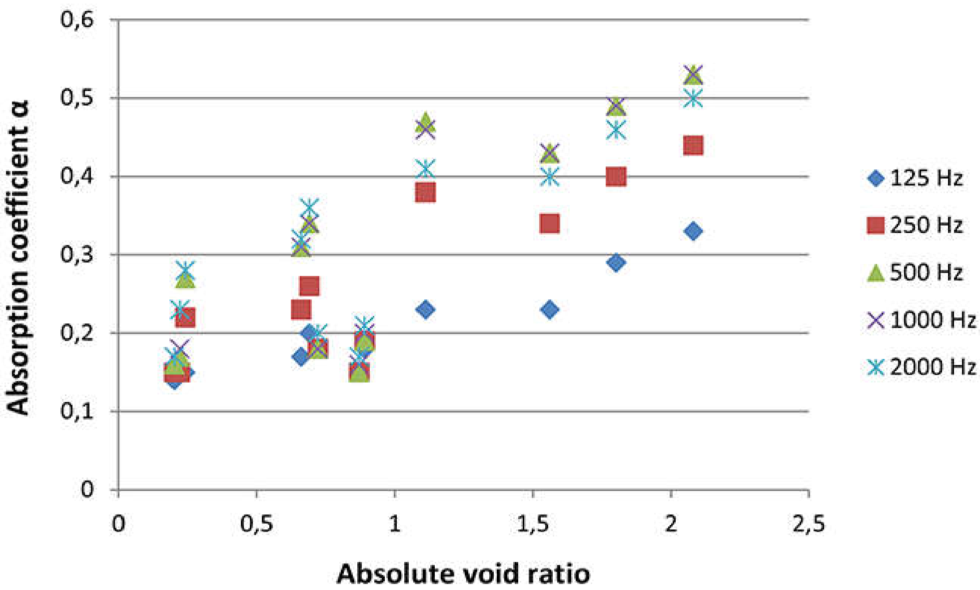


Fig. 6. S1 α=f (Avr)

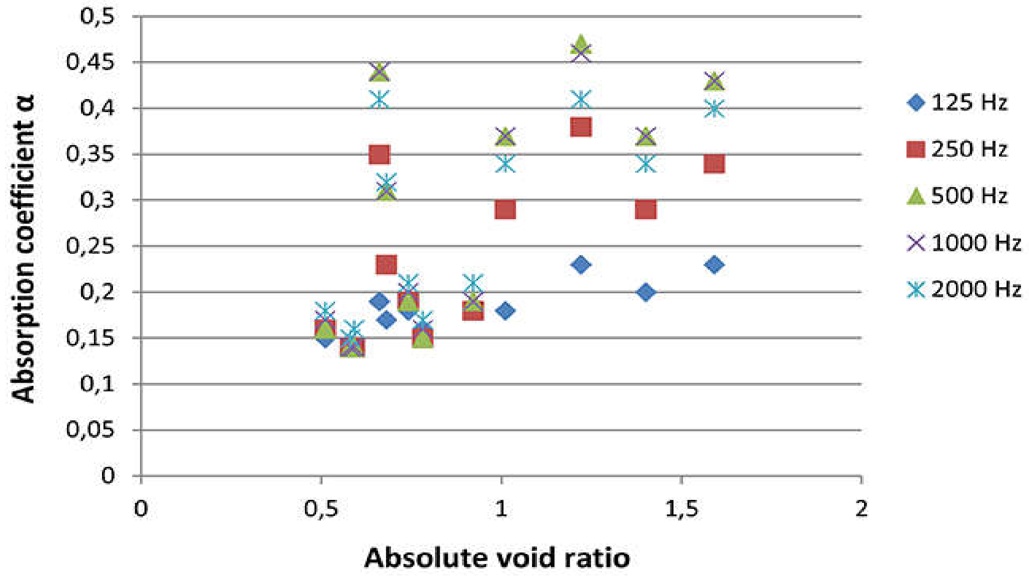


Fig. 7. S2 α=f (Avr)

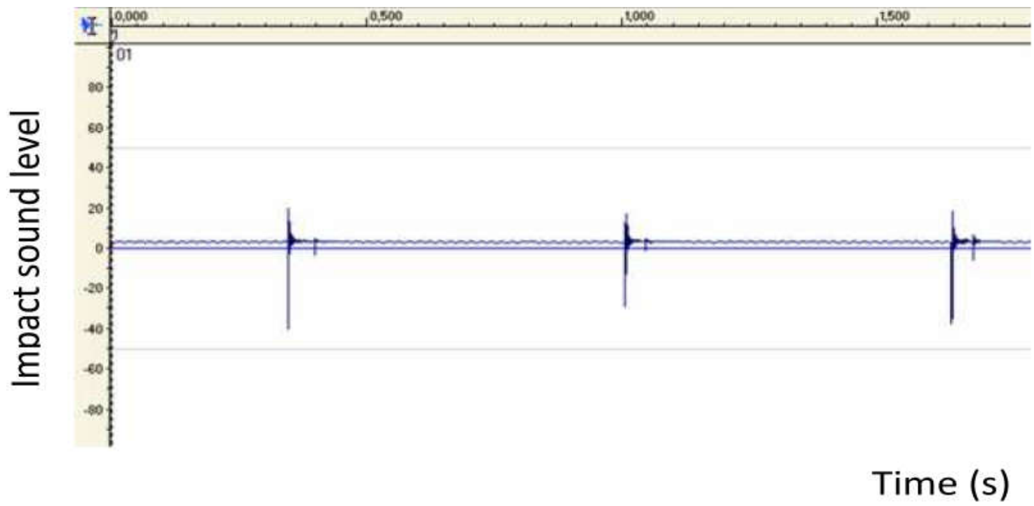


Fig. 8. S1 Longitudinal vibration

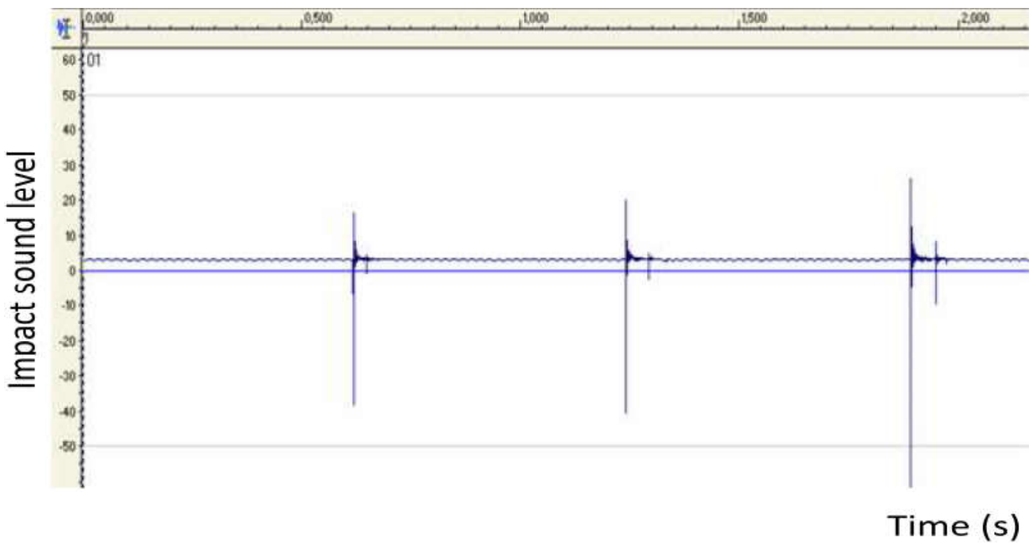


Fig. 9. S2 Longitudinal vibration

Table 7 Absorption coefficient of acoustic bridges as a function of frequencies

Sample	Frequency in Hz				
	125	*250*	*500*	*1000*	*2000*
c5 + air space 1cm + c2	0,81	0,87	0,90	0,92	0,37
c12 + air space 1cm + c10	0,82	0,90	0,93	0,94	0,35
c5 + air space 5cm + c2	0,83	0.88	0.93	0.92	0.38
c12 + air space 5cm + c10	0,85	0.92	0.95	0.94	0.36

Table 8 Approximate ICC rating for a concrete slab c6 or c13 150mm thick with various types of 150mm concrete

Concretes	C6 150mm + c5 150mm	C6 150mm + c2 150mm	C6 150mm + c8 150mm	C13 150mm + c14 150mm	C13 150mm + c10 150mm	C13 150 mm + c17 150mm
IIC values	70	67	72	71	69	73

Table 9. Increase in IIC of c6 and c13 provided by the different concretes according to the slab and according to the surface tested.

	Laboratory test		In situ	
coatings	ISO-8 (12 m²)	Small sample	Finished floor	Small sample
C6 150mm +c5 20mm + c2 20mm	30	30	-	29
2 plates of c6 of 20mm on c2 150mm	7	8	-	8
C6 150mm + c8 40mm	1	3	-	5
Mixed slab with 75 mm of c6 + c2 20mm	-	32	33	-
C13 150mm +c14 20mm + c10 20mm	31	31		30
2 plates of c13 of 20mm on c10 150mm	8	9	-	9
C13 150mm + c17 40mm	3	5	-	7
Mixed slab with 75mm of c13 + c10 20mm	-	33	34	-

This may be due to the nature of the concretes of the sample s2 which has a greater elastic phase than the concretes of the sample s1. Concretes c9, c18, c8 and c17 have absorption coefficients α_{max} ranging between 0.14 and 0.18. The presence of a higher amount of fines in the mixture might be given as a fitting explanation to these observations. A Kundt tube was used to study the absorption coefficient of concrete. Between a concrete and the bottom of the tube, there is an air space of varying thickness. The results are shown in table 7. The creation of the air gap, 3 cm and 5 mm behind the absorbing material, increases the values of the acoustic absorption coefficients especially in the middle frequencies. There is not much difference between the 1cm air gap sample and the 5cm air gap sample. In addition, the prominent peak for different air gap is different. The higher is the gap distance; the maximum is the peak change to a lower frequency.

Acoustic tests induced by shock

Longitudinal vibration : Concrete contains various constituents which form different phases (aggregates, cement matrix, porosity). The percentage of energy transmitted from one phase to another depends on the acoustic impedance in each phase (Penelope, 2008).The acoustic impedance of a material is defined as the product of the density of the material by the speed of propagation of the signals in that phase. It should be noted that the propagation mode of signals can change several times (Dalmay *et al*., 2017). We used concrete slabs to analyze hammer strike sounds applied to multiple faces. Shock tests were carried out according to the following procedure: a concrete slab of rectangular section is slightly embedded in one point and excited with a small hammer of shock to induce a longitudinal vibration to the plate. The perceived sound is analyzed from the software "sound forge", whose height depends on the density of the concrete, as well as the dimensions of the plate. The results obtained from the two samples are shown in Fig 8 and 9. The longitudinal signals generate shear waves or even surface waves because of the different phenomena of refraction and reflection occurring during their propagation in the different phases and vice versa. A more or less long sound trail was still apprehended in the plate depending on whether this plate contains less or more.The presence of scoria seems to modify or even stop the propagation of sound at the cement paste - aggregates interface and consequently provokes energy jumps in the two cases. The distribution of sounds in the sample s2 is characterized by the presence of three sharp peaks with increasing intensity, while the distribution of sounds in the sample s1 is more regular and gradually decreases throughout this phase. One can imagine that the distribution of voids is great in the sample s1 and is almost linear. In the case of sample s2, the events appear only from the frequency 1100 Hz. They are more advanced in the sample s1 at a frequency value of 700 Hz, confirming the linear distribution of the grains.

Impact Insulation Class (ICC): Installing a material between two concrete slabs creates a thin air gap which impairs its acoustic performance. The noise levels are measured and used to calculate the Impact IIC, following the ASTM method E989 (ASTM, 2012). As shown in Table 8, our study indicates that by doubling the concrete panels, it is possible to improve the index IIC which could reach up to 73. To improve the impact sound attenuation achieved by the concrete itself, the concrete placed underneath must be a concrete that dampens the impact. The purposes of Table 9 are, on the one hand, to estimate in situ the IIC values measured in the laboratory, and on the other hand to check whether it is easy, from a small sample of coating, to evaluate its ability to reduce the noise impact over a larger area. The c5 concrete panel, as well as the c2 or c1 panels, can be used as bunches in place of c9 concrete. Indeed, five of the twelve assemblies tested did not contain fines. Of these, two had a FIIC index above 55. It is worth mentioning that the IIC index of a material may vary depending on the type of media on which it is laid. For example, a porous concrete installed on a rigid concrete can increase the index IIC of 5 points whereas no effect is observed on other supports, such as wood floors (Warnock, 1999).

Conclusion

For the studied materials and proportions, based on the average acoustical absorption coefficient, the following conclusions can be drawn:

- Aside from those required in terms of strength in all conditions, the scoria concretes can be used in the field of acoustical insulation;
- While further research is needed to evaluate acoustic performance for other mixing ratios, the results obtained in this work look promising and can be of help for the development of porous concrete made from scoria for use in the building industries and civil engineering.
- The sound absorption coefficient of the materials is influenced by its thickness: the thicker the material, the more it absorbs in the frequency range between 100 and 1600 Hz, and accordingly the peaks move towards lower frequencies. The only precaution to be taken into account is that the density of the material must be accurately measured because the process is sensitive to small variations of this parameter.
- They are relatively inexpensive, providing commercially relevant benefits.
- A less dense and more open structure absorbs noise frequencies below 500Hz and a denser structure works better for frequencies above 1500 Hz.

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