THERMAL AND ACOUSTIC PERFORMANCES OF PORCELAIN STONEWARE TILES

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ABSTRACT

Nowadays there is a growing trend in using radiant floor heating systems for domestic applications, this being one of the most widely used heating systems. Floating tile systems are currently also used in domestic environments in order to reduce walking noise or vibration. Both for thermal and acoustic performances, computer simulations of the effect of several design parameters on the floor heating system and on the floating tile system have concluded that the most important factors are floor material type and thickness. In the present work, the thermal and acoustic properties of four commercial porcelain stoneware tiles having different compositions and/or different thickness were analysed in terms of thermal conductivity and reduction of walking noise. Results showed that noise reduction is strongly influenced by the type of fixing (adhesive or floating tiling) and by the materials coupled with the tiles. Thermal conductivity is directly dependent on the total porosity of the samples.

1. INTRODUCTION

The contemporary progress of innovative building materials is aimed at attaining an efficient building energy management and satisfying the requirements of the thermal and acoustic technical standards [1,2].

Nowadays there is a growing trend in using radiant floor heating systems for domestic applications, this being one of the more widely used heating systems in North European countries [3,4].

Floating tile systems are currently also used in domestic environments in order to reduce walking noise or vibration 2.

Both for thermal and acoustic performances, computer simulations of the effect of several design parameters on the floor heating system and on the floating tile system have concluded that the most important factors are floor material type and thickness.

Traditional ceramic tiles are the basis for modular products which can be applied anywhere, such as new buildings or retrofitting of existing buildings. Porcelain stoneware tiles may be effective floor coverings for radiant floor heating due to their good thermal conductivity compared to other floor coverings like vinyl carpets.

Numerous studies are available in literature on the processing of ceramic tile materials, the viability of different raw materials and new trends. However, their technical properties have scarcely been studied, studies being mainly focused on their mechanical properties. Only few works deal with the thermal and acoustic properties of clay-based materials and even fewer with those of ceramic tiles [5,6,7,8,9].

In the present work, the thermal and acoustic properties of four commercial porcelain stoneware tiles having different composition and/or different thickness were analysed in terms of thermal conductivity and reduction of walking noise. Furthermore, tiles coupled with other materials such as glass fibre were also analysed.

This work represents the starting point for setting up a database of thermal and acoustic properties of commercial porcelain stoneware tiles that will be useful for scientists and professionals of the floor tile market.

2. EXPERIMENTAL

Four commercial porcelain stoneware tiles, referenced A, B, C and D, were selected for the present work. These tiles, Fig. 1, are characterized by different colour and thickness. Their main characteristics are reported in Table I.

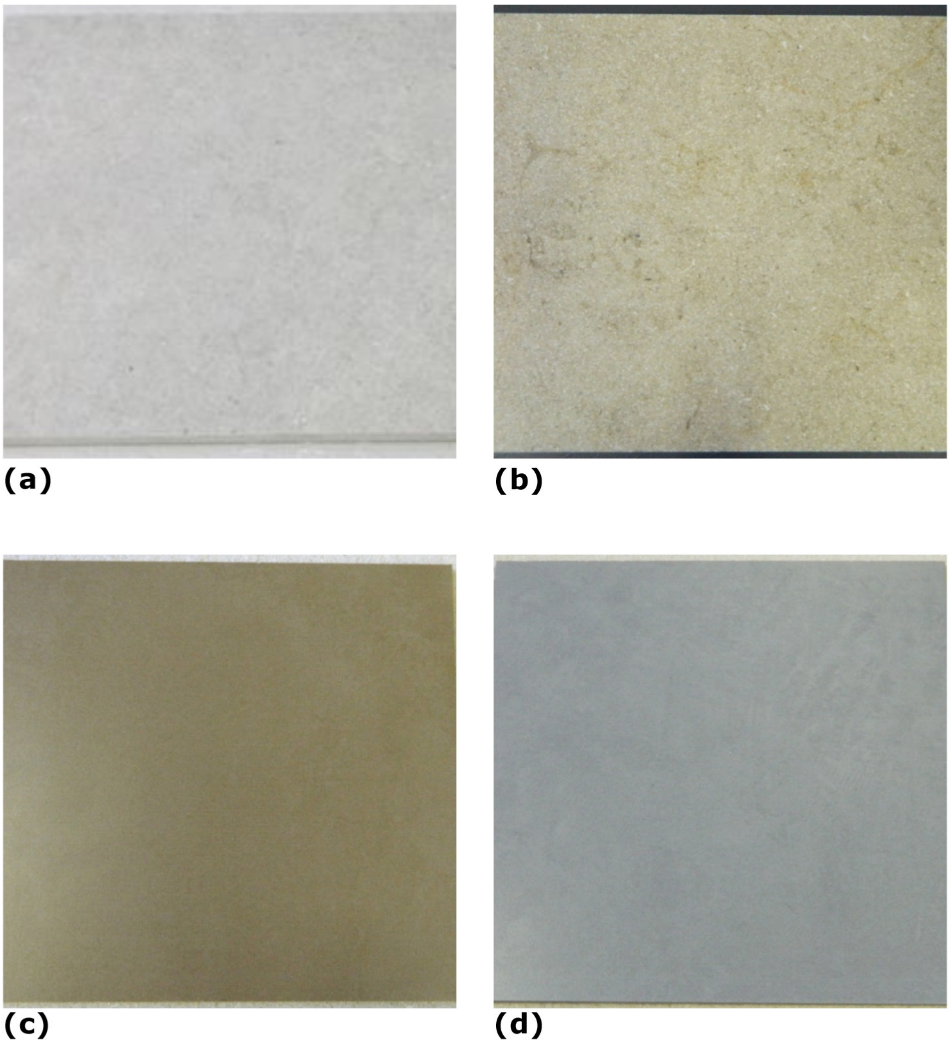


Figure 1: Commercial porcelain stoneware tiles (600x600 mm): sample A (a), sample B (b), sample (C) and sample D (d).

	Sample A	Sample B	Sample C	Sample D
Colour	GREY	BEIGE	BROWN	GREY
Surface finishing	UNGLAZED	UNGLAZED	GLAZED	GLAZED
Size, mm	600X600X14	600X600X10	600X600X5	600X600X4
Material coupled to installation surface	-	-	GLASS FIBRE	GLASS FIBRE

Table I – Synoptic table of the main tile characteristics.

The microstructure of the sample sections was analysed by a scanning electron microscope equipped with an energy dispersion X-ray attachment (Zeiss EVO 40, D and Inca, Oxford Instruments, UK). For the analysis, specimens of about 20x20 mm were polished, by using a diamond dish, and gilded, by using a sputter coater, to make the surfaces conductive.

The hydrostatic density was determined according to standard UNI EN ISO 10545-3 [10] and the total porosity values were calculated on the basis of real density of the powdered samples according to standard ASTM C329-88 [11].

The quantitative mineralogical compositions of the samples were determined by X-ray diffraction analysis (PW3830, Philips, NL). Powdered specimens, diluted with 10 wt% corundum NIST 676 as internal standard, were side loaded to minimize preferred orientation. Data were collected in the angular range 10–80° 2θ with steps of 0.02 and 5 s/step. The Rietveld-RIR refinements were performed using the software GSAS-EXPGUI [12].

The determination of dynamic stiffness was carried out according to standard UNI EN 29052-1 [13] by a resonance method in which the resonance frequency of the vertical vibration of a mass-spring system is determined. The loading mass (steel material) is 200x200 mm in size. The total load on the specimen is 7.5 kg.

The walking noise reduction, ΔL_w, was measured according to standard UNI EN ISO 10140-3 14 and the irradiated noise in the emitting chamber, $L_{n,walk}$, is determined by using a walking machine according to the method described in pr EN 16025 [15]. A standard walking machine (Nor 277, Norsonic) was used in the emitting chamber and the sample was installed on the test floor of the receiving chamber. The walking machine worked on 8 different positions. The generated noise was measured in the receiving chamber after its characterization in terms of echo time by means of the spectrum analysed in the 100-5000 Hz frequency range. The waling noise reduction, ΔLw, is given by the following equation:

$$\Delta L_w = L_{n,r,0,w} - L_{n,r,w}$$

where $L_{n,r,0,w}$ is the evaluation index of the walking noise of the reference floor (78 dB), and Ln,r,w is the evaluation index of the walking noise of the test floor (in dB).

Thermal conductivity tests were carried out in accordance with standard ASTM E 1530 [16] by using the guarded heat flow meter technique.

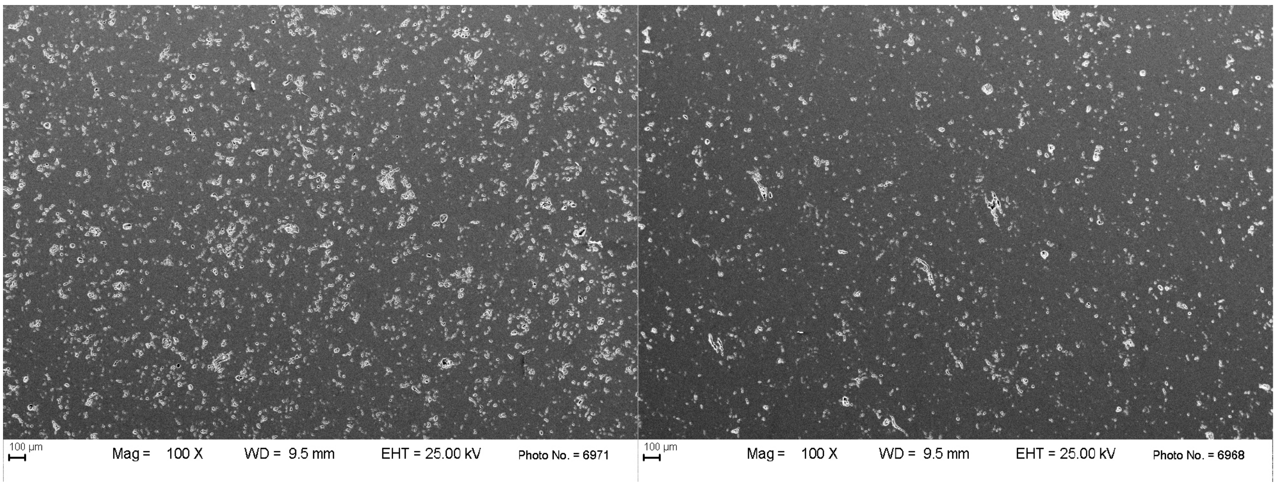
3. RESULTS

The microstructure of samples A and B is rather similar (Fig. 2 a and b, respectively). The pores are homogeneously distributed on both materials. Sample A shows a higher porosity than sample B.

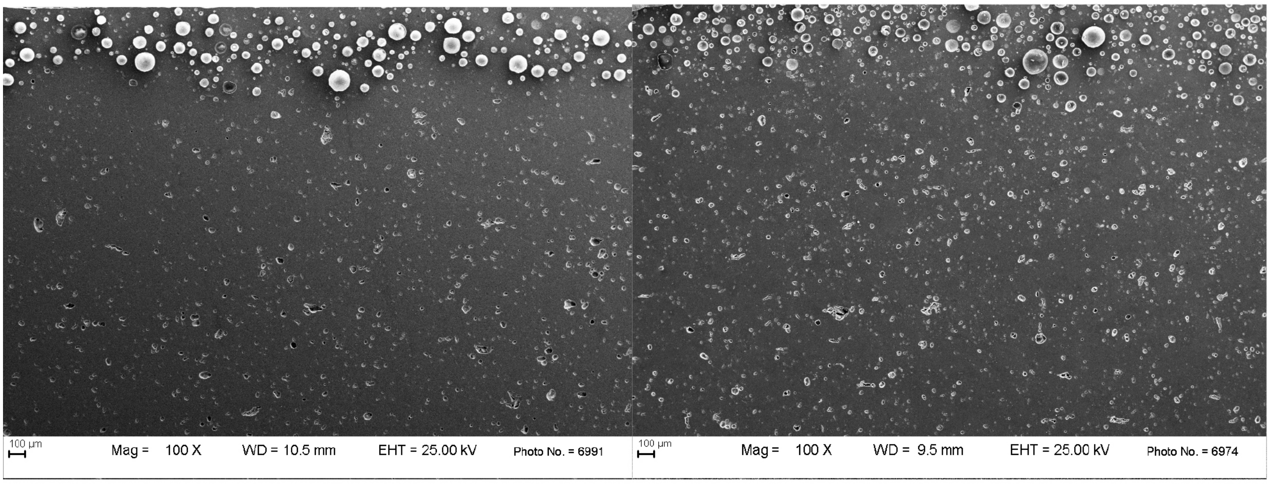
Due to the different surface finish, glazed samples C and D show a concentrated porosity on the external surface of the specimens, which is typical of glazes (Fig. 2 c and d) with round, large-sized pores to about 100 μm. Below the glazed layer the microstructure of both the samples is rather similar with a non-negligible closed porosity characterized by smaller pores with respect to those of the glaze.

The bulk density and closed, open and total porosity of the samples are reported in Table II. Due to the high porosity of the glaze layer, samples C and D are the most porous, with the lowest density values, 2.31-2.32 g/cm^3, respectively. Total porosity in sample C is higher than 9% and in sample D it is higher than 8%. Total porosity in sample A is almost 7%. Sample B is the most compact with the lowest total porosity value, 4%, and the highest density value, 2.38 g/cm^3.

The mineralogical composition of the samples is reported in Table III. In all the samples a similar composition is found and the main differences relate to the amorphous phase that is lower in the unglazed samples A and B (about 65 wt%) and higher in the glazed ones C and D (about 75 wt%). The glazed samples also contain a non-negligible amount of zircon and, in sample D, diopside is also present.



(a) **(b)**



(c) **(d)**

Figure 2: SEM micrographs of the sample sections sample A (a), sample B (b), sample C (c) and sample D (d).

	BULK DENSITY g/cm³	TOTAL POROSITY %	CLOSED POROSITY %	OPEN POROSITY %
Sample A	2.35	6.8±0.1	3.6±0.3	3.2±0.5
Sample B	2.38	4.2±0.1	3.7±0.1	0.5±0.1
Sample C	2.31	9.3±0.1	9.1±0.1	0.2±0.1
Sample D	2.32	8.4±0.3	8.1±0.3	0.3±0.1

Table II – Bulk density and total, closed and open porosity of the samples.

	Muestra A	Muestra B	Muestra C	Muestra D
Cuarzo	20.9±0.1	18.7±0.1	17.1±0.1	14.0±0.1
Mullita	5.1±0.2	6.7±0.3	4.1±0.4	4.3±0.4
Diópsido	0	0	0	3.4±0.3
Plagioclasa	8.1±0.3	8.6±0.5	2.2±0.3	1.3±0.2
Circón	trazas	0	2.0±0.1	1.6±0.1
Fase amorfa	65.9±1.0	65.0±1.1	74.6±1.1	75.4±1.3

Table III – Mineralogical composition (wt%) of the samples.

The dynamic stiffness of the samples is shown in Table IV. The results indicate that samples A and B, without glass fibre, are rather similar. Samples C and D, both coupled with glass fibre, show lower value of about 100 MN/m^3 with respect to samples A and B. Dynamic stiffness seems to be independent of sample thickness or density and strongly influenced by the coupled materials. In fact the dynamic stiffness of sample D without glass fibre is higher and similar to samples A and B. Usually, a high dynamic stiffness value means a low noise reduction.

In Fig. 3 the curves of the noise change as a function of frequency are shown for all the samples and in Table V the evaluation indexes of the walking noise reduction in the frequency range of 100-3150 Hz (according to standard UNI EN ISO 717-2:2007) are reported. As expected, samples A and B, not coupled with glass fibre, show lower values of noise reduction, ΔL, compared to samples C and D, with glass fibre (Fig. 2). Especially for sample D, at elevated frequency, the noise reduction is significantly higher with respect to other samples. It is also confirmed by the highest value of walking noise reduction, ΔL_w. This value seems to be influenced by the material coupled with the samples and by the type of fixing rather than by the thickness and density of the samples.

The thermal conductivity values are reported for all the samples in Table VI. For this test, the glass fibres have been eliminated from the samples due to the risk related to the type of measurement with regard to the air trapped between the plates that may bias the results. The thermal conductivity values thus allow the samples that have a similar composition but a different density to be compared. Sample B, characterized by the highest density and the lowest total porosity, shows the highest thermal conductivity. Sample C with the lowest density and the highest total porosity shows the lowest thermal conductivity. It is confirmed by the literature available on this topic for porcelain stoneware materials [9]. Moreover the values found for this kind of commercial tiles are coherent with the value of thermal conductivity of ceramic tiles with a density of 2.3 g/cm^3 (1.3 W/mK) reported in Table 3 of standard UNI EN ISO 10456[17].

	Sample A	Sample B	Sample C	Sample D	Sample D without glass fibre
s'/t, MN/m^3	667	671	593	580	688

Table IV – Dynamic stiffness, s'/t, of the samples.

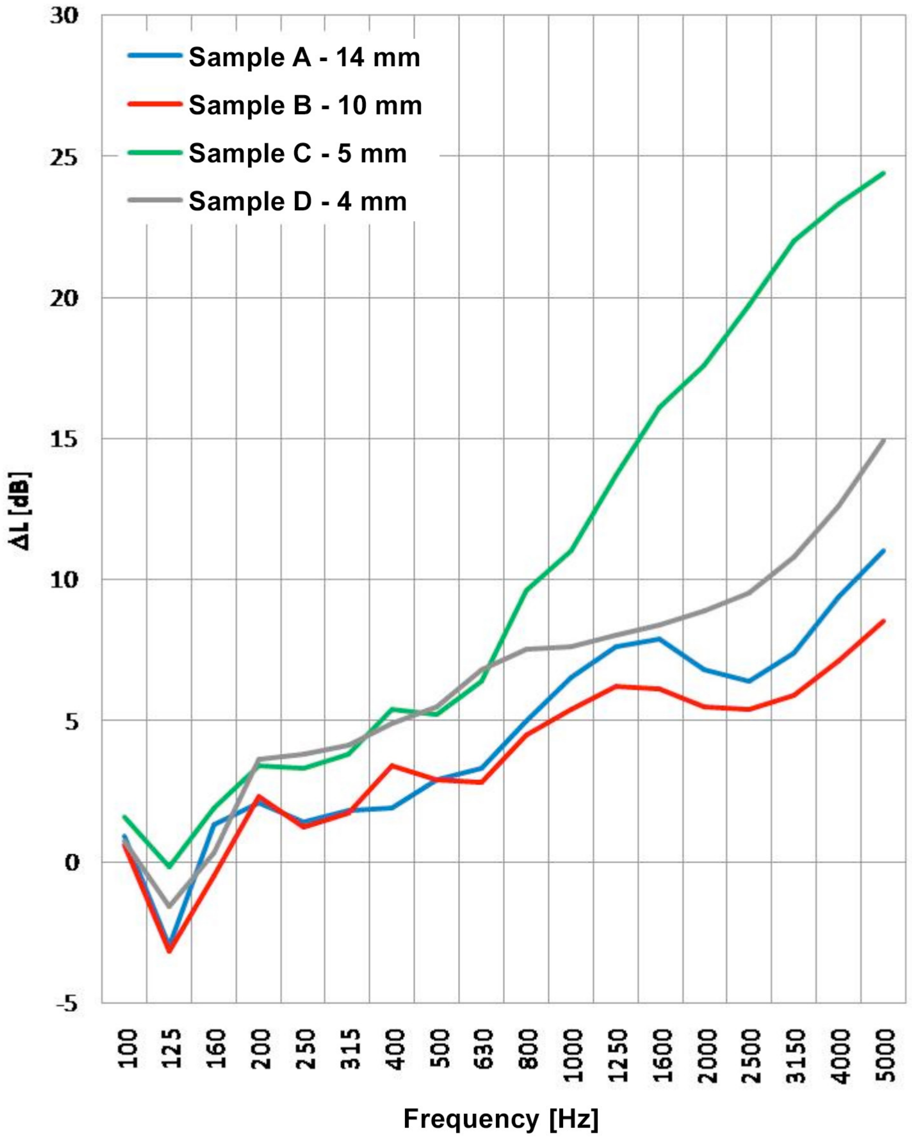


Figure 3: Noise changes as a function of frequency for all the samples having different thickness.

	Sample A	Sample B	Sample C	Sample D
Type of fixing	Adhesive	Adhesive	Floating	Floating
ΔL_w, dB	6	6	15	9

Table V – Evaluation index of the walking noise reduction, ΔLw, according to standard UNI EN ISO 717-2:2007.

	Sample A	Sample B	Sample C without glass fibre	Sample D without glass fibre
λ, W/mK	1.4	1.5	1.2	1.1

Table VI – thermal conductivity, λ, of the sampless.

4. CONCLUSION

The results showed that the dynamic stiffness values are not significantly diverse among the samples with different density and thickness, but non-negligible differences arise if the sample is coupled with glass fibre. Walking noise reduction is strongly influenced by the type of fixing (adhesive or floating tiling) and by the materials coupled with the tiles. Thermal conductivity is directly dependent on the total porosity of the samples. The sample with the highest density is characterized by the highest thermal conductivity.

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