ACOUSTICAL BEHAVIOR OF A NEW LIGHTWEIGHT PARTITION MADE WITH GYPSUM BOARD AND CORK

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ABSTRACT

The building construction development in Portugal has been changed by the very slow but gradual move to a general use of residential partitions made with increasingly light materials from the traditional heavy interior walls. A socioeconomic analysis of the Portuguese situation as it is concerned with the lodging policies and building construction industry, is briefly presented. An international comparison on this matter is shown using some economic parameters. The Portuguese situation is confronted to 37 other countries. The main goal of this paper is to present a study of the acoustical behavior of lightweight partitions, especially those usually called "sandwich-type" and its experimental application to a new and very specific kind of partition made of gypsum board and cork, a traditional material in Portugal. This newly developed sandwich lightweight partition is presented and acoustically characterized. A new and simple mathematical model is presented to evaluate the sound isolation of this kind of partition. The results obtained in reverberant chamber tests are presented as well as the comparisons with the predicted values using the new model proposed. Different single and double wall types were tested giving STC values up to 44 dB.

1. INTRODUCTION

Portugal is the world largest producer and exporter of cork. Nevertheless cork has never been widely used in Portugal in the building construction industry as a sound isolation material. Its main use in this field has been as a thermal insulator or as an acoustic absorptive material.

Cork is a natural product that constitutes the outer bark of a tree named the cork-oak (*Quercus suber L*), that is disseminated all over Portugal (mainly in the southern area). The product is formed by the grouping of cells, in successive layers, each layer being the result of one year's growth. The first cork stripping is carried out only at the end of 20/25 years of life of the tree. The cork stripping is made every nine or ten years. The lifetime average of a cork-oak is about 170 years.

Cork is a unique material thanks to its low specific weight, great elasticity, flexibility and durability, its impermeability to liquid and gases, its resistance to wear and fire, its high mechanical resistance and dimensional stability and resistance to reactive agents, microorganisms, etc.

The world cork production is about 400 000 tons per year and Portugal is the first world producer with 53 %. The second world producer is Spain with 19 %.

The main goal of this paper is to present the acoustical behavior of a newly designed lightweight partition made of gypsum board and cork.

2. RESEARCH JUSTIFICATION

The main use sought for the type of partitions described in this paper is as interior walls in dwellings or office buildings.

The traditional interior wall type in the Portuguese building construction industry has been and still is the heavy 7 cm brick (hollow) wall with 3 cm plaster. This type of solution is more expensive regarding materials used and labor costs than the proposed lightweight partition. However the changing from the traditional heavy walls has been slowly due to the very low labor costs in the Portuguese building construction industry (see Table 1).

The building construction development in Portugal has not followed other western European countries and has been changed by the very slow and gradual move to the general use of partitions made with light materials.

The use of lightweight partitions in the building construction is the standard rule in many western and industrialized countries. This is due mainly to the importance that the labor costs have in the final cost of the building. In Portugal the labor costs are still very low (see Table 1) and this is one reason not to have the same changing move as seen in other countries since many years ago.

In Table 1 is seen that the skilled and unskilled labor costs in Portugal are only higher than some countries in Eastern Europe, Africa, Middle East and Asia. We can note than, for instance, Portugal had in 1991 [3] labor costs 7 to 8 times higher than those in the USA, or 7 to 9 times higher than the ones in Nordic European countries. These values cannot be directly compared due to the difference of levels of life but they can give a clear picture for future developments in this field.

Another aspect to justify the idea that lightweight partitions will be increasingly popular in Portugal is the present costs per square meter for housing. Although the way of life and salaries in Portugal are quite inferior to many other western countries, the housing costs per square meter are not so different that those from these countries. In Table 2 [2, 3] we can see that the costs per square meter for single family housing and apartments or flats are still very low. However the highest values are now just only around 3 times higher than the ones in Portugal.

Building construction in Portugal is not yet as optimized and rationalized than in other countries in Europe or North America. Very low labor costs do not imply a correspondent low final costs per square meter for housing. The use of composite cork and gypsum board in partitions, with a high labor rentability, can then present a lower final cost than the traditional brick wall. This lowering of costs will naturally push down the square meter housing cost in Portugal. As we see in Table 2, the square meter costs in the USA are even lower than in Portugal when labor costs are seven times higher.

Therefore these socioeconomic parameters indicate the interest on having a less expensive and highly effective lightweight partition.

Table 1. Skilled and unskilled labor costs. [2, 3]

COUNTRY	SKILLED LABOR COSTS (/hour)				UNSKILLED LABOR COSTS (/hour)			
	1987		1991		1987		1991	
	National currency	US $	US $	National currency	National currency	US $	US $	National currency
Australia	21	14.0	-	-	20	13.3	-	-
Austria	-	-	25.4	270	-	-	20.7	220
Bahrain	0.62	1.6	-	-	0.45	1.2	-	-
Belgium	795	20.4	-	-	645	16.5	-	-
Canada	22.5	16.7	-	-	19.5	14.4	-	-
Cyprus	-	-	10.4	4.48	-	-	8.4	3.64
Czechoslovakia	-	-	1.5	40.3	-	-	1.1	30.3
Denmark	-	-	28.0	163	-	-	28.0	163
Egypt	3.25	4.6	-	-	0.98	1.4	-	-
Finland	-	-	30.6	112	-	-	21.0	76.7
France	-	-	18.6	95.9	-	-	13.8	71.0
Germany	-	-	15.1	22.8	-	-	-	-
Greece	-	-	15.0	2391	-	-	10.8	1733
Holland	37.2	17.7	-	-	-	-	-	-
Hong Kong	29.5	3.8	-	-	19	2.4	-	-
Ireland	-	-	12.2	6.93	-	-	10.2	5.79
Italy	-	-	25.3	28800	-	-	22.8	26000
Kenya	10.8	0.7	-	-	6.85	0.4	-	-
Luxembourg	-	-	22.2	692	-	-	17.3	540
Malaysia	5	1.9	-	-	2.5	1.0	-	-
Malta			6.4	1.92	-	-	5.3	1.58
New Zealand	19	10.2	-	-	17	9.1	-	-
Nigeria	1.5	0.4	-	-	1.46	0.4	-	-
Norway	-	-	31.4	186	-	-	27.0	160
Poland	-	-	0.9	8186	-	-	-	-
Portugal	**-**	**-**	**4.8**	645	**-**	**-**	**3.8**	515
Saudi Arabia	8	2.1	-	-	5	1.3	-	-
Singapore	8.67	4.0	-	-	6	2.8	-	-
South Africa	8.25	1.8	-	-	2.22	0.5	-	-
Spain	-	-	19.1	1821	-	-	15.0	1428
Sweden	-	-	33.6	190	-	-	32.8	185
Switzerland	51.5	33.2	-	-	34.7	22.4	-	-
Turkey	-	-	0.4	1352	-	-	0.3	825
UK	-	-	11.4	5.89	-	-	9.0	4.63
USA	-	-	37.2	37.2	-	-	26.5	26.5
Zambia	2.34	0.2	-	-	1.97	0.1	-	-
Zimbabwe	2.88	1.8	-	-	1.08	0.7	-	-

Table 2. Estimating costs per square meter for housing. [2, 3]

COUNTRY	SINGLE FAMILY HOUSING (cost / m^2)				APARTMENTS / FLATS (cost / m^2)			
	1987		1991		1987		1991	
	National currency	US $	US $	National currency	National currency	US $	US $	National currency
Australia	375	250	-	-	710	473	-	-
Austria	-	-	-	-	-	-	1240	13200
Belgium	-	-	1058	33k	-	-	1026	32k
Canada	420	311	-	-	410	304	-	-
Cyprus	-	-	394	170	-	-	348	150
Denmark	-	-	1030	6k	-	-	1717	10k
Egypt	-	-	-	-	275	393	-	-
Finland	-	-	-	-	-	-	1412	5150
France	-	-	989	5090	-	-	779	4010
Germany	-	-	819	1240	-	-	1254	1900
Greece	-	-	1001	160k	-	-	826	132k
Holland	1200	571	-	-	1100	524	-	-
Hong Kong	-	-	-	-	2250	288	-	-
Ireland	-	-	529	300	-	-	846	480
Italy	-	-	1055	1200k	-	-	1055	1200k
Japan	-	-	-	-	-	-	2612	350k
Kenya	3600	225	-	-	4k	250	-	-
Luxembourg	-	-	1122	35k	-	-	1603	50k
Malaysia	340	131	-	-	315	121	-	-
New Zealand	790	425	-	-	1075	578	-	-
Nigeria	1500	429	-	-	2375	679	-	-
Norway	-	-	845	5k	-	-	1183	7k
Poland	-	-	444	4250k	-	-	268	2567k
Portugal	**-**	**-**	**504**	68k	**-**	**-**	**630**	85k
Singapore	600	279	-	-	775	360	-	-
South Africa	475	106	-	-	525	117	-	-
Spain	-	-	578	55k	-	-	683	65k
Sweden	-	-	1496	8450	-	-	1169	6600
Switzerland	-	-	1081	1375	-	-	1416	1800
Turkey	-	-	110	344k	-	-	265	828k
UK	-	-	686	355	-	-	821	425
USA	-	-	450	450	-	-	595	595
Zambia	1705	122	-	-	1550	111	-	-
Zimbabwe	240	150	-	-	670	419	-	-

Note: Approximate estimating costs for a particular country are for the normal standards prevailing in that country

3. DESCRIPTION OF PARTITIONS TESTED

Five partitions were tested in this study - four single and one double sandwich partitions (Figure 1):

a) Single partitions

- Partition D1:
Face layers 10 mm gypsum board (each face)

Core	6 mm agglomerated composition cork
Total thickness	26 mm
Total weigh	16 kg/m^2

- Partition D2:

Face layers	10 mm gypsum board (each face)
Core	6 mm rubbercork
Total thickness	26 mm
Total weigh	20 kg/m^2

- Partition D3:

Face layers	10 mm gypsum board (each face)
Core	40 mm agglomerated composition cork
Total thickness	60 mm
Total weigh	20 kg/m^2

- Partition D4:

Face layers	10 mm gypsum board (each face)
Core	ISO500 (2 layers of 25 mm agglomerated composition cork with a 3 mm thick rubbercork sheet in between)
Total thickness	73 mm
Total weigh	24 kg/m^2

b) Double partitions

- Partition DD1/2:

Partition D1 (26 mm) + airspace (100 mm) + Partition D2 (26 mm)

Total thickness	152 mm
Total weigh	36 kg/m^2

Since there was no symmetry in this partition it was tested regarding the sound transmission through both ways of emission named *1* and *2* (DD1/2-1 and DD1/2-2), see Figure.

c) Materials

- Gypsum board - The gypsum board used was a 10 mm thickness composite panel, fabricated with a volume density of about 800 kg/m^3 and a surface density of about 7.5 kg/m^2. Each panel was 1.20 m by 2.80 m (Figure 2).

- Cork - Three types of cork materials were used:

- *Agglomerated composition cork* (or *white agglomerated cork*) - Made of cork granules (1 to 3 mm) bound together under heat and pressure. It has a specific weight of about 125 kg/m^3 and a modulus of elasticity of about 16 kg/cm^2.
- *Rubbercork* - A cork derived material done with different sizes of granulated cork and synthetic rubber (binder: nitrile, neoprene or cloroprene - NBR or SBR). The one used in this study had a specific weight of about 900 kg/m^3 and a modulus of elasticity of about 110 kg/cm^2.

- *ISO500* - Two layers of 25 mm agglomerate composition cork glued with a 3 mm thick rubbercork sheet in between.

4. EXPERIMENTAL PROCEDURES

Transmission loss measurements were performed in the sound transmission facility at the National Laboratory for Civil Engineering (L.N.E.C.) in Lisbon, Portugal. The facility consists of two adjacent reverberation rooms each with a volume of 112 m^3 and a surface area of 140 m^2. The interior dimensions of each chamber were 5.47 m by 4.87 m by 4.20 m. The test opening wall between the rooms was 3.46 m by 2.79 m (Figure 3).

The remaining wall area between the rooms was a double walled concrete construction isolated by cork. The walls, floor and ceiling were made of 0.3 m thick concrete. The double doors to the rooms (0.3 m total width) were made of 0.025 m thick steel sheet with an air spacing of 0.25 m. In each interior facing were glued 0.05 m thick mineral wool sheets.

The diffuseness of a sound field in a reverberation room is dependent upon the number of acoustic modes resonantly excited. For the 112 m^3 reverberation chamber with 1/3 octave bands of excitation there are approximately 14 resonant modes in the 1/3 octave band with a center frequency of 125 Hz. Since the minimum number of modes required for the sound field to be sufficiently diffuse is 20, the measurements done in this frequency band should be treated with some suspicion.

The procedures for measuring transmission loss (TL) followed the Portuguese standard NP-669 (similar to the standards ISO 140 and ASTM E90). The equipment used were 1” microphones Brüel & Kjaer (B&K) model 4145 with preamplifiers B&K 2615 and amplifier B&K 2607.

5. RESULTS

The *transmission loss* (TL) values obtained for each partition tested are presented in Table 4 and Figure 4. The *sound transmission class* (STC), a single-number rating, was calculated according to NP-2073, a similar method as described in ISO 717 and ASTM E413. Table 3 presents the summary of results.

All the partitions show a small drop (critical frequency) near the 160 Hz frequency band. The partition D3 also presents another drop in the TL values for the 1 kHz frequency band.

Table 3. Comparison of Sound Transmission Class (STC) and Transmission Loss (TL) among the partitions tested and the traditional single brick wall.

PARTITION	**STC**	**TL (dB)**	
	(dB)	**minimum**	**maximum**
D1	28	17	31
D2	34	21	39
D3	32	21	45
D4	34	16	44

DD1/2-1 DD1/2-2	44 43	25 24	58 57
Traditional - brick 7 cm	37	27	51

DD1/2 -1 or 2 = D1 + D2 (double) with both ways of emission of sound

Table 4. Transmission Loss (TL) values.

Frequency (Hz)	Transmission Loss (TL) dB					
	D1	**D2**	**D3**	**D4**	**DD1/2-1**	**DD1/2-2**
125	18	24	23	18	27	26
160	17	21	21	16	25	24
200	20	26	25	21	29	28
250	20	27	28	21	32	33
315	22	26	28	27	35	33
400	24	29	28	30	38	37
500	25	29	29	30	42	38
630	26	30	28	33	44	42
800	27	31	27	36	48	45
1000	28	33	24	35	49	47
1250	28	34	31	38	51	48
1600	30	36	38	40	55	54
2000	31	36	41	41	56	54
2500	31	37	45	41	57	55
3150	30	39	45	41	58	57
4000	30	39	44	44	56	55
S T C	**28**	**34**	**32**	**34**	**44**	**43**

6. COMPLIANCE WITH PORTUGUESE NOISE CODE

The Portuguese Noise Code (*Regulamento Geral sobre o Ruído*, Decreto-Lei nº 251/87 from June 24, 1987) in practice since January 1, 1988, states that partitions between rooms in the same dwelling should have a STC greater or equal to 40 dB. Therefore (Table 4) the double partition DD1/2 complies with this law. The traditional brick wall with STC of 37 does not conform with the minimum STC value.

7. MATHEMATICAL MODEL

7.1 Model

A mathematical model was searched for the estimation of the Transmission Loss (TL) for this type of lightweight non homogeneous sandwich partition.

Since the effect of the critical frequency is small in this type of partition and because it will be present in the low end of the frequency range of interest, the developed model will show just one expression for the entire range of frequencies (125-4000 Hz).

The general appearance for the model will be [1]:

$$TL = 10 \log (A.B.C) + D$$

where:

A - term representing the mass effect;
B - term representing the internal damping;
C - term representing the partition stiffness;
D - numerical constant.

Using as the basis for the mathematical elaboration, the work of Cremer and Fahy [4,5] and after some simplifications and mathematical computations [1] the model searched is:

$$TL\ (dB) = 10 \log \left| \left[(m / 700)^{1.5} * f^{2.5} * B^{0.5} \right] - (m^2 * f^{1.5}) \right| - 37.7$$

where the sandwich partition is transformed in one equivalent homogeneous partition. The values for *m* and *B* are then not referred to any of the layers of the sandwich panel but they represent the values for an equivalent homogeneous composite panel.

a) Equivalent mass

$$m = 2\, \rho_1 h_1 + \rho_1 h_2$$

where:

$_1$ - index for face sheet
$_2$ - index for core
ρ - volume density (kg/m^3)
h - thickness (m)

b) Equivalent bending stiffness

The partition equivalent bending stiffness will be found using the following expression [4]:

$$B \approx 2\, B_1 \left[1 + 3\, g / (1 + g) \right]$$

where:

$B_1 = E_1 h_1^3 / 12$
$g = 2\, G_2 / E_1 h_1 h_2 k^2$

and correspondingly

$_1$ - index for face sheet
$_2$ - index for core
G_2 - Core transversal elasticity modulus, $G_2 = E_2 / 2(1+\nu)$
k - wave number, $k = w/c = 2\pi f/c$
E - Modulus of elasticity (Young's modulus) (kg/m^2)
ν - Poisson number

Using the value of 0.3 for the *Poisson number* (reasonable value for the usual building construction materials) and after some mathematical calculation, we get:

$$B \approx (E_1 h_1^3 / 6) + [c^2 E_1 E_2 h_1^3 / (10.4 \pi^2 E_1 h_1 h_2 f^2 + 2 c^2 E_2)]$$

where: $_1$ - index for face sheet
$_2$ - index for core
B - equivalent bending stiffness
c - speed of sound in air (m/s)
E - Modulus of elasticity (Young's modulus) (kg/m^2)
f - frequency (Hz)
h - thickness (m)

To simplify the use of these expressions Table A1 is presented in Appendix where are displayed values for E and ρ for some building construction materials.

7.2 Model Agreement

Table 4 presents the results for the STC values using the described model to this sample of partitions and the differences found to the calculated STC values using the measured TL's. As seen in this table the average difference of +1 dB represents a very reasonable conformity given by the model. The Pearson correlation coefficient (R) between predicted and measured STC's is 0.87. Figure 5 displays four spectra's comparisons between predicted and measured TL's where a good agreement can be seen.

Table 4. Comparison between *STC measured* and *STC model*.

PARTITION	**STC (dB)**		**DIFFERENCE (dB)**
	Measured	**Model**	
D1	28	31	+ 3
D2	34	33	- 1
D3	32	33	+ 1
D4	34	35	+ 1
		Average	+ 1

8. CONSTRUCTION PROCESS

The building of the partitions for this project was done by the cork company in their facilities. It consisted in the gluing of the layers to form the panel. It was used a contact neoprenic glue in the entire surface to be pasted.

Figure 6 presents some details of one of the possible partition assembling processes using the type of material discussed in this study.

9. SUMMARY

The building construction development in Portugal justifies the study of a newly designed lightweight partition done with cork, a traditional material. A socioeconomic analysis about the Portuguese situation concerned with the lodging policies and its building construction industry was briefly presented.

This newly developed sandwich lightweight partition, made with cork in the core and gypsum board in the face layers was presented and acoustically characterized. A new and simple mathematical model was presented to evaluate the TL of this kind of partition. The results obtained in reverberant chamber tests were presented as well as the comparisons with the predicted TL values using the new model proposed. Four different single and one double wall types were tested with giving STC values from 28 up to 44 dB.

The experimental procedure followed and the construction process used in assembling the partitions were also briefly described.

The compliance with 40 dB minimum STC value for partitions between rooms in the same dwelling stated in the Portuguese Noise Code was displayed for the double partition.

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REFERENCES

[1] Carvalho, António Pedro Oliveira. *Estudo Acústico de Divisórias Amovíveis - Análise modelar e desenvolvimento de soluções*. MSc. thesis, U. of Porto, Portugal, 1988.
[2] Davis, Belfield and Everest. *Spon's International Construction Cost Handbook*. E & FN Spon, London, 1988.
[3] Davis Langdon & Everest. *Spon's European Construction Costs Handbook*. E & FN Spon, London, 1992.
[4] Cremer, Lothar. *Theorie der Schalldámmung Dunner Wande bei Scragen Einfall.* Akustische Zeitschrift, 7 (81), 1942.
[5] Fahy, Frank. *Sound and Structural Vibration, Radiation, transmission and Response*. Academic Press, 1985.

APPENDIX

Table A1 - Characteristics of some building construction materials.

MATERIAL	SPECIFIC WEIGHT ρ (kg/m^3)	MODULUS OF ELASTICITY E x 10^8 (kg/m^2)
Aluminum	2700	71-73
Asphalt	1800-2300	8-21
Brick (heavy)	1800-2100	3.1-16.3
Concrete		
heavy	2000-2400	27-29
porous	600-1300	2-3.9
Cork		
agglomerated	100-250	0.0016-0.26
with rubber	800-900	0.011
Glass	2500-2700	61-70
Gypsum board	800	7.14
Iron	7780	210
Lead	11300	17-20
Polystyrene		
expanded	15-30	0.0027
extruded	25-35	0.1-0.3
Wood		
ash	650-880	15
beech	660-800	16
chestnut	550-700	11
fir	400-700	1-5
oak	700-1000	2-10
pine	500-700	1-10
poplar	400-580	7.5
plywood	350-550	5.5
walnut	600-750	14

Figure 1. Partitions tested.

Figure 2. Gypsum board.

Figure 3. Sound Transmission Facility (L.N.E.C. - Portugal).

Figure 4. Spectra of TL for the 6 partitions tested.

Figure 5. Four comparison cases for spectra *TL measured* versus *TL model.*

Figure 6. Assembling process.