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DEVELOPMENT OF FRAMED POPLAR PLYWOOD FOR ACOUSTIC IMPROVEMENT

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ABSTRACT

Acoustic is a fundamental topic in large environments often characterized by poor sound quality such as dining rooms or open space offices. The paper reports the development and testing of sound absorbing poplar plywood for the acoustic improvement of such spaces; prototypes were designed aiming at acoustic performance and lightness, as an alternative to other acoustic wood-based panels currently on the market. The experimentation ranged from the testing of small specimens to the validation of prototypes in end-use dimensions.

Developed panels achieved high sound absorption peaks in the low frequency range (sound absorption coefficient α = 0.80 at frequency of 315 Hz). Prototypes installed on the walls of a dining room reduced significantly its reverberation time (RT_{60}); room users, investigated by a questionnaire, perceived a high acoustic improvement. On the whole the designed products resulted effective sound absorbers; their industrialization can represent a valuable niche for poplar plywood producers.

KEYWORDS: Plywood, sound absorption, Helmholtz resonators.

INTRODUCTION

Acoustic is a fundamental topic in large environments intended for speech like offices, restaurants or dining rooms. Sound quality of such spaces is mainly influenced by two phenomena. Firstly, the simultaneous presence of several voices and listeners originates the "cocktail party effect" (Pollack and Pickett 1957). This expression describes a highly crowded environment in which noise disturbs the conversation and induces talkers to raise their voices; the effect is redundant and results in high background noise and poor acoustic quality (Legget and Northwood 1960). Secondly, large closed spaces with rigid walls are often affected by high reverberation that increases the overall noise (Fasold and Veres 1998).

Many studies reported on poor acoustics of large environments. To mention some example, a survey of college dining halls showed that speech communication is generally poor (White 1999); limited acoustic was found in several restaurants and other dining spaces (Kang 2002); acoustic discomfort has been indicated as a major issue by open space office workers (Jensen and Aren 2005). Therefore, products for the acoustic improvement of these spaces are particularly needed. To be effective they must be adequate for absorbing human voice, which constitutes the main source of noise and is emitted in the low frequency range, particularly between 125 and 1000 Hz (Tang and Chan 1996).

Among the different sound absorbing products available on the market, perforated wood-based panels are particularly appreciated (Cox and D'Antonio 2004). They are generally realized with perforated Medium Density Fiberboard (MDF) and installed as ceiling or walls covering, leaving a space between them and the supporting surface at the back. This cavity can be empty or filled with sound absorbing materials such as synthetic foams that enlarge the absorption range and decrease the frequency peak (Everest and Pohlmann 2009). Surface perforation, instead, aims to absorb sound through the Helmholtz resonance effect (Everest and Pohlmann 2009; Bucur 2006).

In this context, the present paper reports the development and testing of sound absorbing poplar (*Populus* spp.) plywood, that was selected in order to realize lighter acoustic products compared to MDF perforated panels. Poplar wood was chosen both for its lightness and because poplar is the only Italian species for which the offer of raw material can meet the needs of the national plywood industry (Castro and Zanuttini 2008). On the whole the production of sound absorbing elements can represent a valuable niche market for poplar plywood.

MATERIAL AND METHODS

Impedance tube method (EN 10534-2, 2001)

The sound absorption coefficient (α, ranging from 0 when all incident sound is reflected to 1 in case of complete absorption) was determined according to EN ISO 10534-2, 2001 by means of the impedance tube method. Measurements were performed in the low frequency range, i.e. from 50 to 1.600 Hz.

Tests were carried out on circular specimens of thickness 9 mm with diameter 100 ± 0.1 mm, cut from poplar plywood using a CNC machine. Different drilling patterns were tested to individuate the best solution considering both sound absorption properties and CNC machine working times on panels in end-use dimensions.

Holes diameters were 3 or 5 mm, while their number ranged from 1 to 63, for corresponding drilling percentages from 0.32 to 5.67. Each pattern was paired with cavities at the back of thickness 10, 20, 30, 40 and 50 mm; 3 specimens for each combination of drilling pattern and cavities thickness were tested.

Panels production

Eight panels of poplar, 5-layered plywood with density 400 $kg \cdot m^{-3}$ were produced. They were realized in end-use dimensions of 2120 x 1250 x 9 mm. Panels were drilled with a CNC machine in order to replicate the perforation patterns tested by the impedance tube. Holes diameters were 3 mm and 5 mm and drilling percentage was set to 1.41. Each panel was installed on a poplar plywood frame of thickness 40 mm, with a reinforcing central rib. Two polyester sound-absorbing mats with density 40 $kg \cdot m^{-3}$ and thickness 30 mm were laid within the frames (Fig. 1).

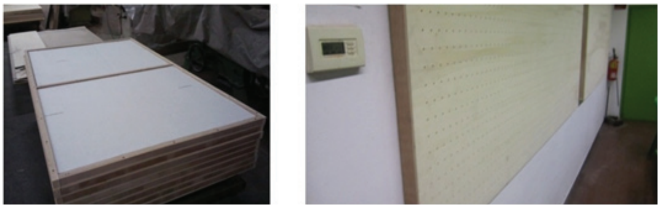

Fig. 1: Framed panels produced on the basis of impedance tube results: back of the panel filled with sound absorbing mats (left) and detail of a panel installed in end-use application (right).

Reverberation room (EN ISO 354, 2003)

Sound absorption properties of large panels were determined in reverberation room according to EN ISO 354, 2003. Two panels with holes diameters 3 mm and 2 panels with holes diameter of 5 mm were tested, for a total samples surface of 10.6 m^2.

Testing a final application (dining room)

In order to validate the prototypes in a final application, sound absorbing panels in end-use dimensions were installed on the walls of a dining room of a small-medium enterprise (SME). Selected room represents a typical example of a large environment with sound reflecting surfaces (rigid walls, PVC coated ceiling, wide windows) that determine high reverberation and poor acoustic quality. The volume of the environment is 243.81 m^3, with an overall surface of 231.55 m^2; air temperature during measurements was 19.4°C. Four panels with holes diameters of 3 mm and 4 panels with holes diameters 5 mm were installed in the room with a uniform distribution on its walls, for a total samples surface of 21.2 m^2.

Absorption properties were investigated according with EN ISO 3382, 2012, while tests and results analysis were performed on the basis of EN ISO 354, 2003. Reverberation time RT_{60}, that is the time required for a sound to fall in intensity by 60 dB, was calculated according to the above reference standard.

Questionnaire

Taking as a reference the method adopted by Goujard et al. (2005), a questionnaire was prepared to evaluate how users perceived the acoustic effect of panels installed in the dining room.

The questionnaire was anonymous and was addressed to workers of the small medium enterprise (SME) in which the prototypes were installed. It was submitted after lunch break in the room arranged with 8 panels (21.2 m^2) on the walls. Four tables and 14 users were in the room: This represents a typical situation of an industrial dining room of a SME, where users' number is usually in the order of magnitude of tens.

The questionnaire assumed users were not aware of detailed acoustic issues. Four questions were asked:

In the room with panels on the walls (compared to the room without panels):

1. can you hear better during conversation?
2. do you think that the background noise is lowered?
3. do you think that the environment is more acoustically comfortable?
4. if you noticed any improvement of acoustic comfort, rate it from 1 (small) to 5 (high).

RESULTS AND DISCUSSION

Impedance tube method (EN 10534-2, 2001)

Results of testing on small scale specimens are reported in Tab. 1.

Tab. 1: Sound absorption peak values determined by means of the impedance tube method.

Holes diameter (mm) / drilling (%)	Cavity (mm)	10	20	30	40	50
3 / 0.32	Value (α)	0.67	0.78	0.81	0.91	0.92
	Frequency (*Hz*)	286	208	160	144	128
3 / 1.41	Value (α)	1.00	0.96	0.94	0.90	0.83
	Frequency (*Hz*)	616	426	354	306	268
3 / 5.67	Value (α)	0.80	0.66	0.59	0.55	0.52
	Frequency (*Hz*)	1,176	878	692	602	548
5 / 0.32	Value (α)	0.68	0.86	0,93	0.96	0.98
	Frequency (*Hz*)	238	168	136	118	106
5 / 1.41	Value (α)	0.99	0.93	0.88	0.83	0.91
	Frequency (*Hz*)	570	418	340	290	266
5 / 5.67	Value (α)	0.70	0.55	0.47	0.42	0.39
	Frequency (*Hz*)	1,152	816	652	586	508

Absorption values resulted from 0.39 to 1.00 at frequencies from 106 Hz to 1.176 Hz. According to Helmholtz resonators physics, increasing in thickness of cavities at specimens back determined a shift of the absorption peaks towards lower frequencies (Everest and Pohlmann 2009). Patterns with holes diameter of 3 and 5 mm, drilling percentage of 1.41 and paired with cavities of 40 mm were selected as the most interesting combinations (Fig. 2).

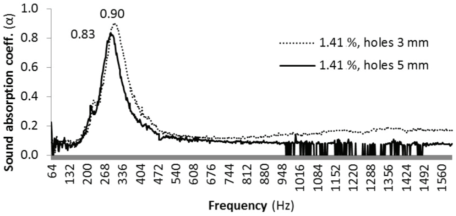

Fig. 2: Sound absorption coefficient α measured in impedance tube for specimens with drilling percentage of 1.41 and circular holes with diameters of 3 and 5 mm respectively.

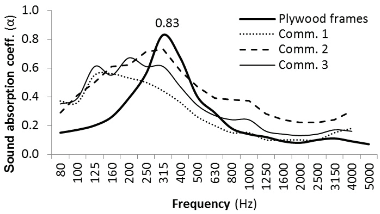

Fig. 3: Sound absorption coefficient determined in reverberation room for developed plywood frames (holes Ø 3 and 5 mm, drilling 1.41 %, cavity 40 mm, mat 40 mm) and absorption properties of three commercial panels (Comm. 1: 3 mm, 0.6 %, 200 mm, 30 mm; Comm. 2: 3 mm, 1.1 %, 200 mm, 30 mm; Comm. 3: 3 mm, 2.3 %, 200 mm, 30 mm).

The above combinations present several advantages: the absorption peak values are respectively of α 0.83 and α 0.90, comparable with those of several products on the market; peak frequencies lay around 315 Hz (306 and 292 Hz), that is within the human voice frequency range; perforation percentage of 1.41, compared to higher percentages, reduces CNC working times needed to drill panels in end-use dimensions.

It must also be noted that the absorption behavior is quite selective around the resonance frequency. Enlargement of curves, together with a reduction of peak values, can be obtained by filling the cavity with sound absorbing materials (Fasold and Veres 1999). This practice was adopted for large panels tested in reverberation and dining rooms.

Reverberation room

Fig. 3 shows the sound absorption properties determined in reverberation room for plywood frames with drilling percentage of 1.41; the absorption curves of three commercial panels with similar characteristics, produced in dimensions 60 x 60 cm by an Italian manufacturer, are also reported.

The peak value determined for plywood frames is of $\alpha = 0.83$ and lays at 315 Hz, within the human voice range. Compared to selected commercial panels, developed frames resulted more selective around the resonance frequency and particularly effective for specific sound correction between 250 and 500 Hz; further, as above mentioned, their absorption curve can be enlarged by increasing the thickness of cavity and of the filling mat.

Testing in a final application (dining room)

Reverberation time RT_{60} for the room with and without panels is reported in Fig. 4.

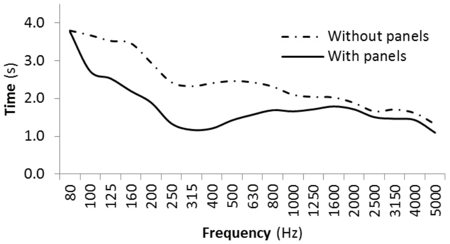

Fig. 4: RT_{60} measured in the dining room with and without panels.

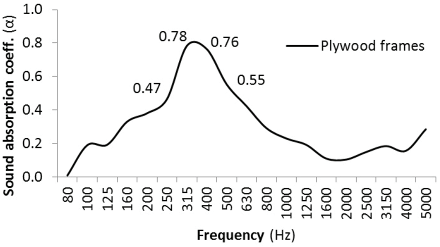

Fig. 5: Sound absorption coefficient measured in the dining room.

T-test was performed for comparing reverberation times measured the in room with and without panels. Significant differences for $p < 0.05$ were found for frequencies of 2500, 4000 and 5000 Hz; significant differences for $p < 0.01$ were found for all other frequencies with the exception of 80 Hz. RT_{60} resulted almost halved at 315 Hz, where it decreased from 2.32 s to 1.17 s, and 400 Hz, where it varied from 2.40 s to 1.21 s. Optimum reverberation time is a subjective parameter that depends on room and users expectations, anyway in large rooms intended for speech it can be estimated lower than 1.5 s (Kuttruff 2009), therefore the above values can be considered as satisfying.

Finally, Fig. 5 shows the sound absorption coefficient measured in the dining room. Results are in accordance with those obtained in reverberation room: the peak value lays at 315 Hz ($\alpha = 0.78$) and the shape of the absorption curve is similar, slightly shifted towards higher frequencies. These minor differences can be attributed to the non-standardized testing conditions (effect of furniture and windows, adherence of frames to the walls etc.) occurring in a real environment such as the selected dining room.

Questionnaire

All users answered the questionnaire and answered "yes" to question 1-3. Fig. 6 illustrates users' answers to questions 4, expressed as a percentage.

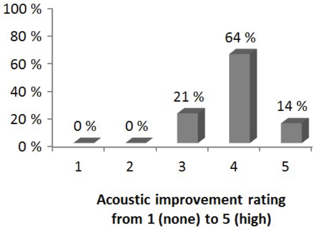

Fig. 6: Users answers, expressed as a percentage, to questions 4.

It is worth to note that a complete acoustic recovery of the dining room would require a proper acoustic design of the room and the addition of other sound absorbing frames (Kuttruff 2009), which would result in an even higher appreciation by users.

CONCLUSIONS

Developed panels turned out effective for absorbing sound in the low frequency range, where they achieved absorption peaks higher than α 0.80 at 315 Hz. Results obtained through standardized experimental methods were confirmed by testing in a dining room. Reverberation time of the room with panels resulted significantly lower than that of the room without them. Room users, inquired with a questionnaire, showed high appreciation of panels effect.

On the whole poplar plywood was found suitable for producing sound absorbing elements. Other than for its acoustic properties, perforated poplar plywood guarantees a remarkable lightness of the end-product, particularly in comparison with other wood-based materials used for the same purposes; the absence of a rear face further reduces the overall weight of developed frames. The industrialization of the above prototypes could enable plywood manufacturers to find new niche markets in order to differentiate their production and to develop high added-value products.

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