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ORIGINAL RESEARCH PAPER

STUDIES AND RESEARCH CONCERNING THE USE OF SOME RECYCLABLE ABSORBENT MATERIALS FOR INCREASING ACOUSTIC COMFORT INTO A ROOM DESIGNED FOR SPEAKING

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Abstract: The acoustic comfort of a speech hall is characterized by acoustic parameters. These parameters depend by on the hall volume, construction and design materials. On the hall ceiling (the most unused surface), some various acoustic devices can be installed on which the acoustic materials can be applied in order to obtain specific suitable acoustic parameters for that hall. Recycled materials such as wood, granular recycled rubber, shredded recycled plastic and shredded polypropylene, applied on various acoustic devices made from OAS, polystyrene or plasterboard rigips, can increase the acoustics quality of room.

Keywords: *hall acoustic comfort, recyclable materials, sound absorption parameters*

INTRODUCTION

The construction and design of hall materials must have some specific proprieties but also are characterized by chemical and material science characteristics (domain). For these reasons, new materials are design and studied to achieve specific acoustics characteristics for enclosed spaces [1].

The sound frequency range for human hearing (audio frequencies) is in the 20 ÷ 20000 Hz range, but speech understanding is achieved in a limited range, respectively 500 ÷ 2048 Hz. The materials and structures that can absorb or attenuate the sounds with frequencies from this range are used in the hall construction and design to achieve an acoustic comfort [2].

The materials used in the hall construction and design, utilized for different activities, can be classified into two categories [3, 4]: materials that improve the sound quality, known also as absorbent materials and acoustic isolators, which are designed to reduce the sound to propagation outside of the closed space.

The acoustically absorbent materials are useful when is necessary to control the acoustic energy, in order to retain it inside the hall. These materials must reduce the transmitted energy. The acoustic absorbing materials will act in the field of reflected energy, and the acoustic insulation materials will act in the field of transmitted energy. An absorbent material can differ by density from the insulating material [4 – 11], respectively: absorbent materials with low density and flexible (fiberglass, mineral wool), acoustic foam (polyurethane, melamine) and textiles (polyester, cotton); the insulating materials with high density and rigid (concrete and ceramic blocks, some metals), or medium density (plasterboard, wood, rubber, bitumen).

All materials and objects that are in a hall have a lower or higher acoustic absorbent properties. Therefore, the most important “material” from a room is the interior air. The furniture curtains and people from that hall have also acoustic absorbent properties.

The air absorption produce an acoustic energy attenuation effect [8], therefore, it must be taken into account for high frequency sounds when is calculating the hall reverberation time (T60). In small hall, air absorption can be neglected, but for large rooms where the T60 is high, air absorption determines a significant acoustic energy reduction. Absorption of air depends on the sound frequency.

The furniture, materials used for hall decorations, interior people and other objects can considerably contribute to sound waves absorption [12]. These natural absorbents are usually porous absorbents, which absorb high frequency waves. When is calculating the reverberation time (T60), must be taken into account of the materials absorption by multiplying the surface with their absorption coefficient. The result is the equivalent of the absorbent area. Surface of objects cannot be measured in square meters. Their absorption capacity it is measured and expressed directly as an absorbing surface equivalent [13]. The absorption coefficients are determined for the sound frequencies in the 125 ÷ 4000 Hz range.

The acoustic parameters measure the temporal relationships of acoustic energy degradation curve and give information about the hall quality (destination), speech or music listening.

From the reverberation parameters, the reverberation time (T60) is the main parameter that expresses the acoustic hall quality (is an objective parameter) [14]. It expresses the hall "vivacity" and is related to the geometric characteristics of the room (volume, surface), but also to the properties of the materials used in the hall construction and design [15, 16].

The energy parameter group analyzes the sound energy and characterizes the room in terms of clarity regarding the speech and music perception, speech definition, central time or room sound. In fact, these parameters express a balance between the sound energy that is perceived earlier by the receiver and the sound energy that is later perceived [17]. Speech clarity (C) is a parameter related to speech intelligibility and shows the separation degree between different sounds from an oral message [18]. This parameter is divided into clarity of voice (C50) and clarity of music (C80). In conversation halls (classrooms, conference rooms, amphitheaters, theaters), speakers need to be understood without difficulty. These hall characteristics can be determined according to its destination.

The definition (D) is the ratio of energy perceived by the receiver in the first 50 ms and the total energy transmitted by the source. The 50 ms value is representative for the speech.

The central time (Ts), called also “center of gravity” of the pulse response energy (of the decreasing curve), measures the time from the curve beginning to the “gravity center” of the decreasing curve. A low value indicates that most of the energy comes early, while a high value suggests that the energy comes late, according to the direct sound. Low value suggests a perception of clarity, while a high value indicates a reverberant sound [1, 15, 19 – 26].

The intelligibility parameters refer to:

- the unspoken consonants (% AlCons) percentage is the lost consonants percentage (not perceived) by a receiver (listener) at a distance from the sound source [15, 16, 25, 27, 28];
- the Rapid Speech Transmission Index (RASTI) is a parameter associated with speech intelligibility [16, 18, 25, 27, 29, 30].

Acoustic parameters can also be determined by calculation, based on the absorption coefficient and can be determined for unpopulated and populated rooms [1, 13, 15, 17, 25, 31, 32], according to equations (1) – (6):

$$T60 = \frac{0.16 \cdot V}{Ab_{tot}} \tag{1}$$

$$C50 = 10 \cdot \lg\left[\exp\left(\frac{1.04}{T60}\right) - 1\right] \tag{2}$$

$$D50 = \frac{1}{1 + 10^{-\frac{C50}{10}}} \tag{3}$$

$$Ts = \frac{T60}{13.815} \tag{4}$$

$$\%\ AlCons = 9 \cdot T60 \tag{5}$$

$$RASTI = 0.9482 - 0.1845 \cdot \ln \%\ AlCons \tag{6}$$

where: *T60* is the reverberation time (s); *V* is the room volume (m^3); Ab_{tot} is the total room sound absorption, considering the room objects and persons; C50 is the clarity of voice (dB); *D50* is the speech definition (dB); *Ts* is the central time (s); *% AlCons* is the unspoken consonants (%); *RASTI* is the Rapid Speech Transmission Index.
The total sound absorption of the room (Ab_{tot}) depends on the absorption coefficient α_{med} and the total area of the room walls (S_p), all the room objects (S_{ob}) and persons (S_{tot}). It is measured in Sabini and represents the sound absorption for a 1 m^2 surface (equation 7):

$$Ab_{tot} = \sum_1^n \alpha_i \cdot S_i \qquad (7)$$

MATERIALS AND METHODS

Sampling and preparation for experiment

To determine the main acoustic parameters of a speech room, designed with different materials, the following considerations were considered:

- a room with an atypical geometry was chosen, *i.e.* the ratio of length (L) / width (l) / height (h): L x l x h = 19.55 m x 4.65 m x 2.72 m, *i.e.* a 247.27 m^3 volume, which is a special case for a room (the optimal ratio is 2.6 / 1.6 / 1) [4];
- recyclable absorbent materials were chosen to analyze their acoustic qualities;
- it was considered that the room ceiling is the main absorbent surface and that can be modified as surface and sound absorption coefficient;
- the room furniture was taken into account to determining the total absorbent area, but the room was considered unpopulated;
- the absorbent materials have been fixed on the support materials to form of acoustic devices mounted on the room ceiling.

The materials selection for the study was carried out with the environmental protection requirements aim, respectively the use of biodegradable and recycled materials, to ensure a room acoustic comfort. The determination of the acoustic absorption coefficient for the chosen materials was performed in the anechoic chamber (the impedance tube) from the "Gheorghe Asachi" Technical University of Iasi.
The used support materials were: OSB/3 plates (pressed wood rigid boards); expanded polystyrene, EPS 50; normal plasterboard Rigips brand.
On the three types of support materials were applied several types of materials with different acoustic qualities. The materials used as a backing layer are recycled materials: synthetic materials (recycled rubber granules, shredded recycled plastic, recycled polypropylene granules) and mixed materials (wood pellets made by using of a synthetic binder).
For the granular materials an ecological binder, biodegradable produced by SC Romchim Protect SA Bacau, according to his own recipe, was used. Its composition is based on water-based acrylics, fillers, additives and cellulosic thickener. All recycled granular materials mixed with the organic binder were applied to the sample supports except for the polystyrene expanded support where it was necessary to apply a mortar layer.

Figure 1 presents the images of the samples analyzed in the anechoic chamber (the impedance tube) [33, 34].

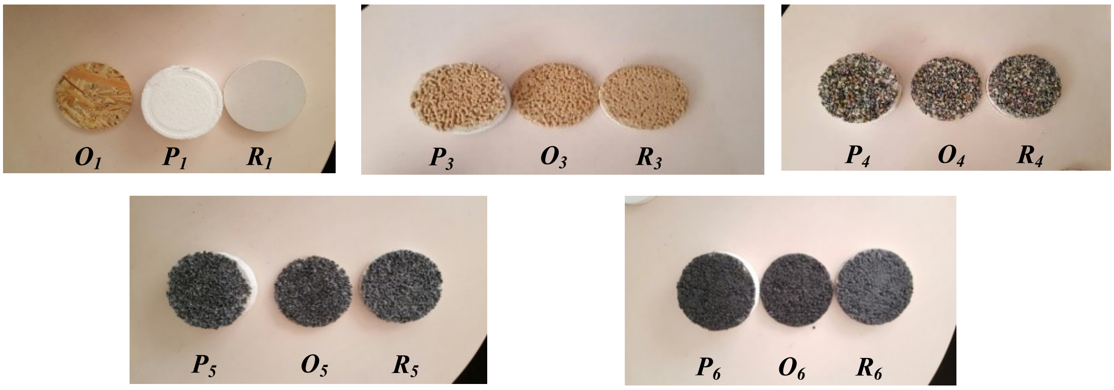

Figure 1. *Samples analyzed in the anechoic chamber (O_1 – OSB; P1 – polystyrene; R_1 – plasterboard-rigips; P_3 – polystyrene with applied coating and organic binder with wood pellets; O_3 – OSB with organic binder and wood pellets; R_3 – plasterboard-rigips with organic binder and wood pellets; P_4 – polystyrene with organic binder and recycled plastic particles; O_4 – OSB with organic binder and recycled plastic particles; R_4 – plasterboard-rigips with organic binder and recycled plastic particles; P_5 – polystyrene with coating, organic binder and recycled polypropylene; O_5 – OSB with organic binder and recycled polypropylene; R_5 – plasterboard-rigips with organic binder and recycled polypropylene; P_6 – polystyrene with ecological binder mixture and recycled rubber granules; O_6 – OSB with ecological binder mixture and recycled rubber granules; R_6 – plasterboard-rigips with ecological binder mixture and recycled rubber)* [12, 33, 34]

The total room absorption (Ab_{tot}) was calculated for the ceiling equipped with acoustic devices (applied with studied sound absorbent materials). The sound absorbent area for each working variant was 459.25 m^2, consisting of the room area 386.8 m^2, to which are added two surfaces of 36.225 m^2 each (corresponding to the sound devices). The studied acoustic materials and the total room absorption (A_{bi} = 21.601 m^2) was added to the acoustic devices absorption (A_{bd}) (Table 1).

Table 1. *The calculated reverberation time for all material and acoustic devices working variants*

No.	**Sample code**	**The material of the acoustic device mounted room ceiling**	**The absorbtion surface room + devices [m^2]**	**Absorption coefficient, α**	**Total absorbtion, Ab_{tot} [m^2] = A_{bi}+ A_{bd}**	**Calculated reverberation time, T60c**
1	V1	Empty ceiling	386.8	0.05585	21.601	1.62
2	O_1	Simple OSB	+ 72.45	0.08	27.397	1.444
3	P_1	Simple polystyrene	+ 72.45	0.076	27.035	1.463
4	R_1	Simple plasterboard-rigips	+ 72.45	0.106	29.208	1.355
5	O_3	OSB + wood pellets mixed with ecologic binder	+ 36.225 + 36.225	0.106 0.08	28.339	1.396

No.	Sample code	The material of the acoustic device mounted room ceiling	The absorbtion surface room + devices [m^2]	Absorption coefficient, α	Total absorbtion, Ab_{tot} [m^2] = A_{bi}+ A_{bd}	Calculated reverberation time, T60c
6	P_3	Polystyrene + wood pellets, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.1 0.076	27.941	1.416
7	R_3	plasterboard-rigips + wood pellets, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.13 0.105	30.117	1.314
8	O_4	OSB + recycled plastic granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.11 0.08	28.484	1.389
9	P_4	Polystyrene + recycled plastic granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.12 0.076	28.665	1.380
10	R_4	Plasterboard- rigips + recycled plastic granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.14 0.105	30.477	1.298
11	O_5	OSB + recycled polypropylene granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.116 0.08	28.701	1.378
12	P_5	Polystyrene + recycled polypropylene granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.121 0.076	28.701	1.378
13	R_5	Plasterboard-rigips + recycled polypropylene granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.147 0.105	30.73	1.287
14	O_6	OSB + recycled rubber granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.112 0.08	28.556	1.385
15	P_6	Polystyrene + recycled rubber granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.114 0.076	28.448	1.391
16	R_6	Plasterboard-rigips + recycled rubber granules, mixed with ecologic binder, on one side	+ 36.225 + 36.225	0.144 0.105	30.621	1.292

RESULTS AND DISCUSSION

The calculation reverberation time (T60c) determined by the simplified relation of Sabine (equation 1) had values in the range of 1.287 ÷ 1.62 s, compared to the empty room ceiling, where the highest reverberation time was 1.62 s. In the case of all other working variants lower reverberation times' values were obtained (Figure 2).

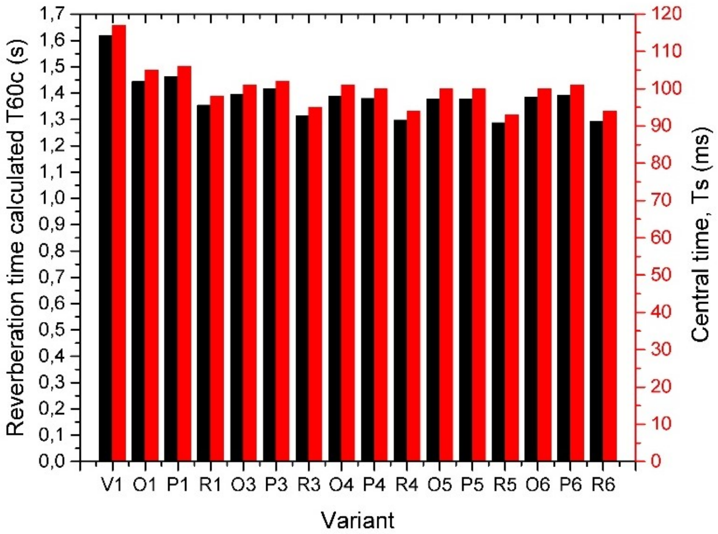

Figure 2. *Variation of T60 and Ts parameters for anechoic room studied materials which can be used in the room ceiling arrangement*

The use of recycled binder and recycled polypropylene applied on plasterboard-rigips (R5) led to the highest reduction of reverberation time (1.287 s). The second best reverberation time reduction (1.292 s) was obtained by using recycled rubber granules applied on plasterboard-rigips (R6).

The central time (Ts), an important energy parameter, had the same variation as the reverberation time (T60), within the range of 93 ÷ 117 ms. For the same working variants (R5 and R6) were obtained the lower values (Figure 2), respectively 93 ms for the case of ceiling arrangement with the plasterboard-rigips sound devices covered with recycled polypropylene granules, in mix with organic binder (R5) and 94 ms for the same acoustic devices but covered with recycled rubber granules (R6).

For speech clarity (C50), the obtained values were ranging from -0.456 to 0.947 dB. Compared to the empty room ceiling (V1), where the speech clarity was of -0.456 dB, the highest values (close to 1) was obtained for the same R5 and R6 working variants (Figure 3).

The speech definition (D50) had the determined values in the range of 0.474 ÷ 0.554 dB. For all acoustic devices working variants (the use of all materials), the speech definition (D50) was values above the admissible value. The below the allowable value was obtained in the case of empty room ceiling (V1) (Figure 3).

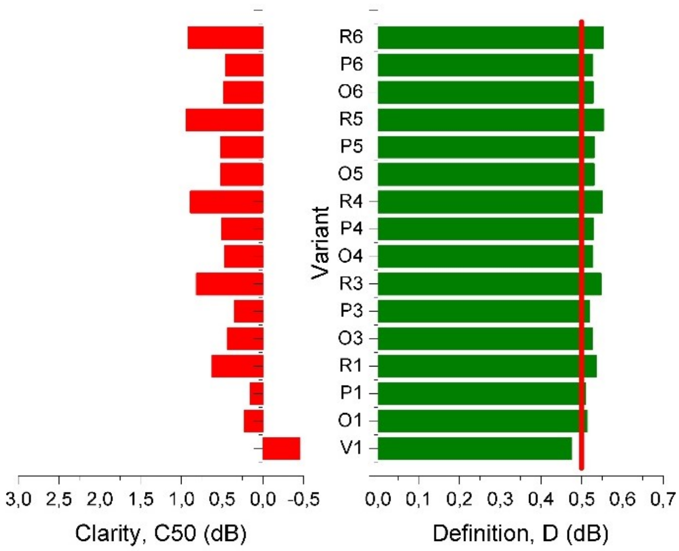

Figure 3. *Variation of C50 and D parameters for anechoic room studied materials which can be used in the room ceiling arrangement*

From the speech intelligibility parameter group, only the RASTI and % AlCons parameters were studied. The speech intelligibility was lower for the V1 working case (empty room ceiling) and acceptable for other working variants, ceiling arrangement with the acoustic devices covered with the studied materials (Figure 4).

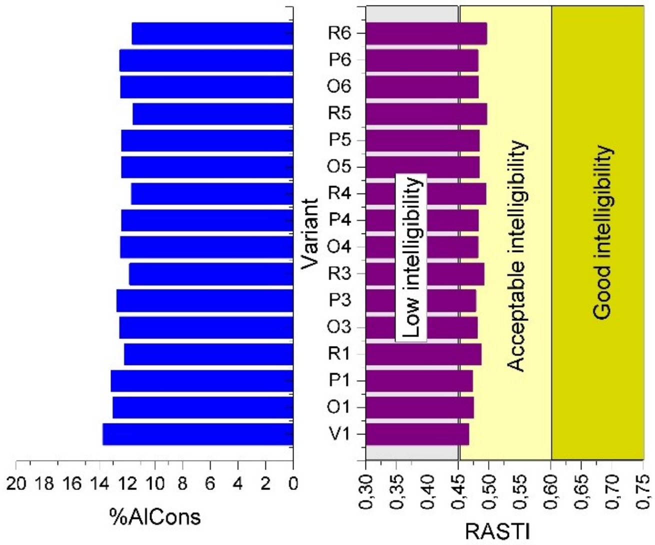

Figure 4. *Variation of % AlCons and RASTI parameters for anechoic room studied materials which can be used in the room ceiling arrangement*

The % AlCons decrease from 13.74 %, for the case of empty room ceiling, to 11.583 % for R5 working case (Figure 4).

CONCLUSIONS

The analyzed materials used to cover the acoustic devices were those studied in the anechoic chamber (the impedance tube) at which the absorption coefficient were determined by measurements.
All acoustic parameters determinations were realized in furnished room, but unpopulated.
For anechoic chamber studied materials (in the impedance tube), reverberation time (T60) was determined by calculation using Sabine's equation.
The speech clarity (C50), in all studied materials working variants, characterizes the room as "acceptable acoustics" properties.
The sound definition (D50) had values above the minimum allowable value (0.5 dB) for all versions of the room ceiling acoustic devices arrangements, compared to the empty room ceiling, where the admissible value was not obtained.
Central time (Ts) depends directly by T60 and indirectly on C50. The values were in the tolerable range (72 ÷ 144 ms) for all working variants.
The the smallest values of % AlCons was obtained in the case of plasterboard-rigips acoustic devices use, covered with recycled polypropylene granules mix with organic binder (R5) followed by R6 and R3 studied cases.
From the RASTI parameter point of view, which characterizes the room intelligibility speech, all the acoustic devices uses perform a room intelligibility increasing from the "poor intelligibility" class (empty room ceiling V1 working variant) to "acceptable intelligibility" class.

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