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Ethylene vinyl acetate (eva) aggregates usage evaluation for lightweight concrete subfloor to reduce impact sound in flooring systems

Desarrollo de una losa de piso de hormigón liviano con agregados reciclados de acetato de vinil etileno para reducir el impacto sonoro en los sistemas de piso

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Abstract

Civil construction, nowadays has to deal with comfort and habitability requirements and raw material lack. Thus, it is desired to reuse materials. In this context, the subfloor plays an important role in providing users with comfort, being an interesting object of analysis. Thus, this study aims to design lightweight concrete slabs with ethylene vinyl acetate (EVA) aggregates for subfloors, with two grain sizes of conventional sand replaced with EVA. The experimental program is composed of four unit mixes, three of them varying the ratio between EVA coarse and natural fine aggregates, and the one with higher quantity of EVA coarse aggregates was replaced sand for EVA fine aggregates. The subfloor slabs were molded with three thickness of 3, 5 and 7 centimeters, and a set of 3cm slabs plus 1cm of conventional coating. Slabs were submitted to specific mass tests and L'nT,w mean standardized impact sound pressure level tests. Results showed a correlation between two variables, being that 7cm thickness slabs with smaller specific mass, with total aggregate replacement, presented noise intensity reductions of 17dB in comparison to 7cm slabs with natural sand and smaller content of EVA coarse aggregate; and 28dB reduction in relation to the reference.

Keywords: *EVA waste, reduce solid waste, acoustic performance, impact sound, flooring systems, lightweight concrete*

Resumen

Actualmente, la construcción civil lidia con los requisitos de confort, habitabilidad y escasez de materia prima, por lo que se busca reutilizar los materiales. En este contexto, las losas de piso juegan un papel importante para entregar a los usuarios la comodidad buscada. Por lo tanto, este estudio intenta diseñar losas de hormigón liviano usando agregados de acetato de vinil etileno (EVA) en las losas de piso, usando dos granulometrías de arena convencional sustituidas con EVA. El estudio comprende cuatro mezclas: en tres de ellas se modifica la relación entre los agregados gruesos de EVA y los agregados naturales finos; y una cuarta mezcla, la con mayor cantidad de agregados gruesos de EVA, en la que la arena fue reemplazada por agregados finos de EVA. Las losas de piso se moldearon con espesores de 3, 5 y 7cm, y un conjunto de losas de 3cm más 1cm de recubrimiento convencional. Las losas fueron sometidas a pruebas de masa específica y a ensayos de nivel promedio de la presión del ruido de impacto estandarizado, L'nTw. Los resultados mostraron correlación entre las dos variables, resultando que las losas más delgadas de 7cm de espesor, de menor masa específica y reemplazo total del agregado, presentaron una reducción de la intensidad del ruido de 17 dB en comparación con las losas de 7cm que contenían arena natural y menor contenido de agregado grueso de EVA; y una reducción de 28 dB en relación con la losa de referencia.

Palabras clave: Residuo de EVA, reducción de residuos sólidos, comportamiento acústico, ruido de impacto, sistemas de piso, hormigón liviano

1. Introduction

Among the sectors, civil construction is thought to be one of the most productive for the economic and social development of a region. However, environmental impacts resulting from the consumption of natural resources or the generation of waste are a contemporary problem, and there must a balance among them, as a way of not compromising environmental sustainability (Yemal et al., 2011).

Civil construction supply chain accounts for 20% of plastic material consumed in the world, being the second most important industry, after packaging (Magrini, 2012). Taking into account that part of such consumption is transformed into waste in urban areas, the relevance of civil construction is considerable. Thus, studies to reuse these materials or other waste in components of building products or systems are justified.

It is possible to use lightweight concrete, as a viable alternative to incorporate polymeric waste at construction. Besides not overloading structures, this solution has mechanical impact properties in flooring systems and consequent impact sound reduction in the lower pavement (Herrero et al., 2013; Brancher et al., 2016).

The use of polymeric waste in cementitious composites is the object of researches whose focus restricts to properties regarding the use as a fiber; however, the incorporated quantity is reduced, if compared to the use of polymer in the form of grains or aggregates. Saikia and Brito (2012) complement that the disadvantage of adding polymers to cementitious matrixes is that it represents a reduction of mechanical properties and an increase of the elasticity module, leading to more deformations. Nonetheless, it presents an improvement in thermal insulation and in acoustic performance (Herrero et al., 2013). Recent results also point out the need of new studies to assess granular polymeric waste incorporated to cementitious-base matrixes.

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It is known that concrete with EVA ethylene vinyl acetate as a substitute to the use of conventional aggregates, brings air incorporation through the component own porosity, being an efficient method to provide concrete with acoustic insulation (Bistafa, 2006).

EVA is one of the main inputs in the leather-footwear industry, used to produce soles for shoes. This material is supplied in reduced thickness boards and variable widths. For footwear production these boards are cut off, which generates leftovers, leading to disposal costs for the company that generated the waste and also to environmental impacts.
The Brazilian civil construction industry is adapting to ABNT NBR 15575: 2013 – Performance Standard. This standard presents through qualitative requirements and quantitative criteria, the acoustic performance required for housing among others. The sector investigates alternatives to comply with acoustic performance requirements for buildings, with competitive solutions that allow for the proper disposal of waste coming from other industries.

In this scenario, added to the need of using polymeric waste, the goal of this study is to analyze different EVA solid ratios and grain sizes in the development of lightweight concrete subfloor slabs, in order to mitigate the impact sound in flooring systems, with two types of replacements, one being with the coarse aggregate grain size only and the second with total replacement, both of crushed stone and sand, with the latter being replaced with EVA fine fraction.

2. Insulation impact sound in floors

∫The EVA polymer is composed of a high technology mix of ethyl, vinyl and acetate, with the mechanical behavior of an elastomer, and reversible elongation in a long strip of deformation at room temperature (Karpinski et al., 2009).

The insulation of impact sound in overlapping rooms receives an efficient treatment through floating floors, composed of a resilient base among two rigid plates, floor slab and coating. These flooring systems use resonance and damping concepts to reduce vibration in the rigid base and increase the acoustic insulation (Hassan, 2009), and this principle is broadly used in independent layers systems. However, this same principle can also be met with the incorporation of resilient materials in cementitious mixes. According Maderuelo-Sanz et al. (2011), materials used for this purposes are based on polymers, which allow broad reuse and recycling possibilities.

These materials promote a mass reduction in flooring systems and are susceptible to deformations, which may lead to changes in the damping capacity over time. This approach was investigated by Miškinis et al. (2012), who found differences in the mechanical impact damping capacity, with high damping losses in fibrous materials in open-cell materials, comparatively to closed-cell materials. Besides, Peters (2012) points out that different types of resilient materials used in vibration damping show different behaviors due to sound frequency, such as cork, cork-based composites, felt, polymeric foams and elastomers, which may be used in the form of liners or plates, in high frequencies, for which the static deflections are reduced.

Low density, open-cell materials may have deformations due to permanent compression, besides presenting wear and tear problems in the coating joints. On the other hand, closed-cell materials show a pneumatic effect caused by air contained in its interior. All of these materials have part of their elasticity determined by the way the air behaves when the material is compressed. (Dikavicius and Miskinis, 2012; Stewart and Craik, 2000).

According Fahy and Walker (2015), the use of resilient bases in buildings has certain specificities, when compared to the use in isolated equipment. Impact sound insulation must provide bases that are rigid enough to assure stability during the use of flooring system; however, they will have their insulation capacity reduced when compared to softer materials. Thus, acoustic and mechanical properties for these materials must be equally considered (Stewart and Craik, 2000).

In this sense, studies proposing compounds with cement, natural aggregate and/or light aggregates have been designed to characterize and analyze the technical viability of different types of mixes. Differences caused by a higher water absorption in lightweight aggregates are indicated as the main concern in the proposal of new cementitious materials and more specific tests to characterize these aggregates are still in a discussion (Deshpande and Hiller, 2011). Especially for the use in flooring systems with concrete slab, studies about the influence of lightweight aggregates porosity (Deshpande and Hiller, 2011; Ribeiro et al., 20014), the type of lightweight aggregate used (Branco and Godinho, 2013; Ben Fraj et al., 2010), and of polymeric waste grain size (Herrero et al., 2013); indicate that the adequate characterization of these aggregates may determine the control on the flooring system acoustic performance regarding impact sound.

Concerning flooring systems requirements, ABNT NBR 15575 (2013) sets performance acoustic levels, as minimum (M), intermediary (I) and superior (S), according to Table 1. These requirements must be met in all housing buildings.

Table 1. Performance acoustic levels for flooring systems

Element	$L'_{nT,W}$ (dB)	Performance acoustic levels
Flooring systems separating autonomous housing units in different floors	66 a 80	M
	56 a 65	I
	≤55	S

3. Experimental program

The experimental program included the aggregates characterization, concrete dosage, subfloor slabs molding and the impact sound test, with two types of replacement of natural aggregates for EVA. In the first stage, natural coarse aggregates (crushed stone) were replaced for EVA in the mix, in the equivalent grain size. In the second stage, the coarse aggregates replacement was maintained, besides partially (50%) replacing fine aggregates (sand) for EVA.

3.1 Materials characterization

3.1.1 Cement

It was chosen to use high initial resistance cement, whose values of strength, beginning and end of setting and waste retained in the #75μm sieve are in compliance with thresholds set forth by Standard (ABNT NBR 5733:1991) and are presented on Table 2.

3.1.2 Fine aggregates

The sand used as fine aggregate shows characteristics featured on Table 3.

3.1.3 EVA aggregates

It was carried out coarse and fine EVA aggregates characterization for dimensional, tactile, particle size distribution and unit mass analyzes. Results obtained in the materials characterization are presented on Table 4.

Table 2. Cement characterization

Mechanical properties	Results	Chemical properties	Results
Sieve #200 (75mm)	0.19	Insoluble waste (%)	0.76
Sieve #325 (45mm)	1.69	Fire loss (%)	3.04
Blaine (g/cm^2)	4351	Al_2O_3 (%)	4.04
Beginning of setting (min)	163	SiO_2 (%)	19.16
End of setting (min)	212	Fe_2O_3 (%)	2.63
1 day strength (MPa)	20.2	CaO (%)	60.56
3 days strength (MPa)	34.2	MgO (%)	4.70
7 days strength (MPa)	40.3	SO_3 (%)	2,16
28 days strength (MPa)	49.3		

Table 3. Finel aggregate characterization

Aggregate	Maximum diameter	Fineness modulus	Water absortion	Specific gravity	Unit mass
Sand	4.8mm	2.92	0.30%	2.51g/cm³	1.54g/cm³

Nota: Este valor pareciera ser bajo para la absorción de una arena convencional, por favor revisarlo

Table 4. EVA aggregates characterization

Properties	Coarse EVA aggregate	Fine EVA aggregate
Fineness modulus [20]	1.08	0.6
Maximum modulus [20]	4.8	2.4
Average density (mm)	9.5	0.3
Tactile analysis	Uniform and deformable	Uniform and slim
Unit mass [22] (g/cm³)	0.37	0.21

3.2 Slabs dosage and thickness

For the comparative analyzes of lightweight concrete and thickness, three mixes in volume were carried out (cement: fine aggregate: EVA coarse aggregate): 'a', 'b' and 'c'. In mix 'd', it was counted on a higher use of EVA aggregates, considering there was also a partial replacement (50%) of fine aggregate for EVA of similar grain size. For each unit mix three levels of subfloor slab thickness were defined, being that for the 3cm-thickness slab, a 1cm conventional mortar coating was tested, simulating finishing. Dosage is shown on Table 5.

It was observed the proportion between aggregates and cement is always the same, 1:5. What varies from one mix to another is the EVA fine and coarse aggregate ratio. Mixes 'c' and 'd' are those with the highest big aggregate ratio, which tends to create hollow spaces among the elements, once the quantity of sand used is not enough to fill the space among bigger aggregates. The difference between unit mixes 'c' and 'd' is that, in the former the fine aggregate is river sand, while in the latter there was a partial replacement (50%) of it for EVA crushed fine aggregate.

3.3 Slabs molding and impact sound test

A variable height mold was used to manufacture the slabs, for the application of pressure in the four extremities of the set, through the use of threaded bars, nut and washer. For the execution of slabs with 1cm of coating, initially mortared coating was laid and later the filling with lightweight concrete was performed. After concreting, the slabs were taken out of the mold, then 24h of curing and sent to a temperature and humidity controlled room with a 23 +/- 2°C temperature and 100% of relative humidity, until the date set for the acoustic test, the 28 days.

A performance standard (ABNT NBR 15575:2013) points out the impact sound test procedure referenced by ISO 140-7- Field Measurements of Impact Sound Insulation of Floors and ISO 717-2- Impact Sound Insulation for the assessment of results. Tests were performed in overlapping rooms, separated by reinforced concrete slabs with 10 cm thickness, with masonry walls and solid bricks coated with mortar. The emitting and the receiving rooms have a 16.24 m² floor area and 44.82 m³ volume. The tested sample was of 1m², which was constituted of four 50 cm x 50 cm slabs. The samples reduced dimensions met cost reduction, time and waste production requirements designed by this research (MIŠKINIS et al. (2012)).

For noise generation, Bruel & Kjaer model 3207 (Figure 1) standardized tapping machine source was used. The measurement equipment was the sound level analyzer from Quest Technologies model 2900, class 1, with an octave band filter, in three different positions, as shown in Figure 1.

***Table 5.** Samples mixes and thickness*

Sample	*Mix*	*Thickness (cm)*
a(3)	1:1.5:3.5	3
a(3+1)	1:1.5:3.5	3+1
a(5)	1:1.5:3.5	5
a(7)	1:1.5:3.5	7
b(3)	1:1:4	3
b(3+1)	1:1:4	3+1
b(5)	1:1:4	5
b(7)	1:1:4	7
c(3)	1:0.5:4.5	3
c(3+1)	1:0.5:4.5	3+1
c(5)	1:0.5:4.5	5
c(7)	1:0.5:4.5	7
d(3)	1:0.5:4.5	3
d(3+1)	1:0.5:4.5	3+1
d(5)	1:0.5:4.5	5
d(7)	1:0.5:4.5	7

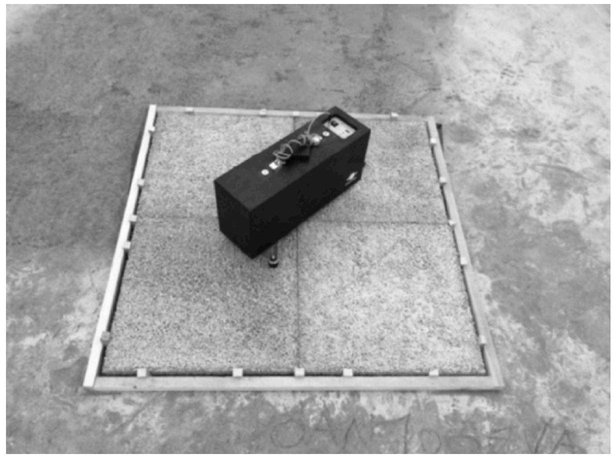

Figure 1. *Tapping machine positioned on samples*

4. Results and analysis

4.1 Slabs specific mass

The samples of subfloors specific mass tests (ABNT NBR 9778:2009) were performed after 28 days of setting, and results are shown on Table 6.

It is realized the higher the quantity of EVA coarse aggregate, in relation to the fine aggregate, the smaller the specific mass, due to a higher number of hallow spaces among bigger particles. Even the 1:0.5:4.5 unit mix presented a specific mass 35% smaller than the 1:1.5:3.5 mix, with a 417.7 kg/m³ reduction. The 3cm lightweight concrete slabs with 1cm coating were not considered in the calculation, once they are added with conventional mortar. There was a slight variation in specific mass values among slabs with the same mixes, due to the slab production process.

4.2 Impact Sound Test

Results obtained in the impact sound test are shown on Figure 2, grouped by mix used.

Table 6. *Specific mass tests of samples*

Samples	Specific mass (kg/m³)	Average specific mass (kg/m³)
a(3)	1157.0	1197.4
a(5)	1179.3	
a(7)	1255.9	
b(3)	1071.4	1112.0
b(5)	1111.9	
b(7)	1152.6	
c(3)	803.0	779.7
c(5)	719.8	
c(7)	816.3	
d(3)	739.5	729.1
d(5)	745.4	
d(7)	702.5	

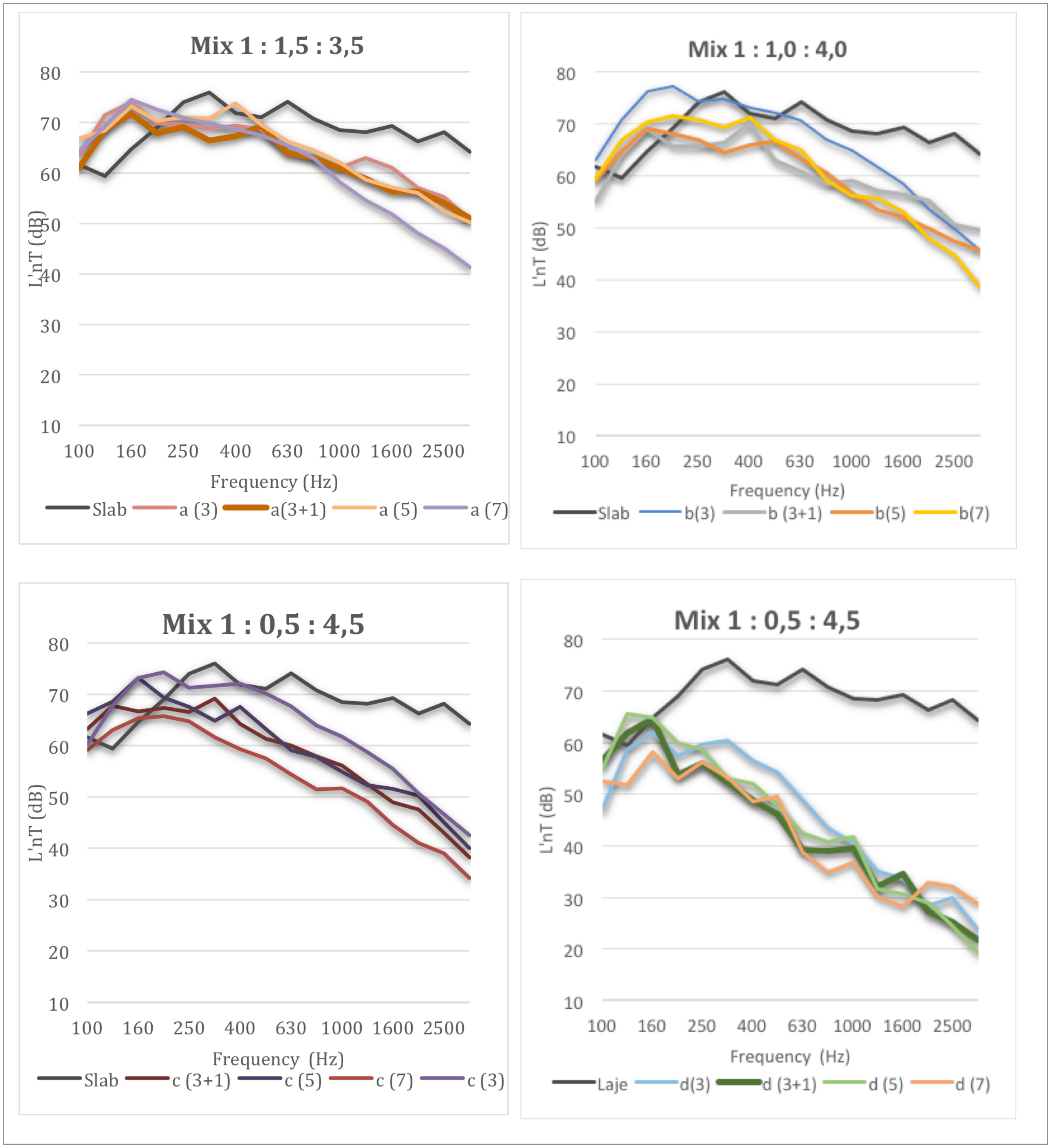

Figure 2. *Values of impact noise by frequency in samples of lightweight subfloor boards*

All samples met the acoustic performance required, through impact sounds that are lower than the reference concrete slab acoustic performance, showing the technical viability of EVA aggregate use to replace conventional ones for this purpose. Values measured point to a higher reduction of sound levels in frequencies from 630Hz for all compositions that were studied. With this behavior, the EVA aggregate maintains the pneumatic effect of mechanical damping reduction, even with the grain surfaces in contact with cement paste.

Among the variables that were analyzed, differences in ratios of conventional and EVA aggregates were determinants to the samples' acoustic performance, except for the 3cm thickness, which showed certain constancy. Other thickness levels present higher impact sound values for smaller specific masses, that is, for a smaller quantity of EVA coarse aggregate. This behavior intensified for the 7cm thickness, as observed in Figure 2. Figure 3 shows mean impact sound pressure levels for samples that were tested.

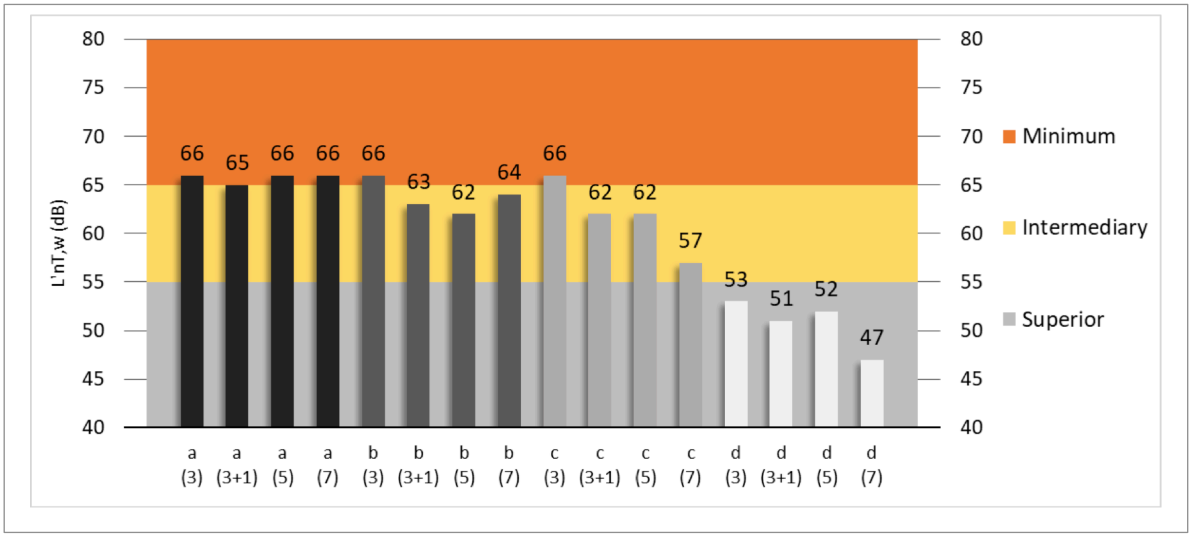

Figure 3. *Values of $L'_{nT,W}$ for lightweight subfloors and conventional slab*

The gradual evolution of sets due to an increase of EVA big aggregate ratio in the composition is perceptible. In addition, slabs with the best performance were those in which there was a total replacement of coarse aggregates and partial replacement of fine ones, reaching values of 47dB for 7cm-thickness slabs. It was observed a correlation between the specific mass values and impact sound, which can help in future studies, using a more economical and faster method to analyze acoustic performance in slab systems.

Finally, it is possible to rank the systems studied based on ABNT NBR 15575:2013. The reference slab is classified as minimum performance, while EVA coarse aggregates and natural fine aggregates systems ('a', 'b' and 'c' mixes) are classified as having an intermediary performance. Slabs containing EVA coarse aggregates only and those with partial fine aggregates ('d') are classified as higher performance slabs.

5. Conclusion

After assessing the samples, it is possible to conclude that:

- *The incorporation of EVA aggregates in concrete is an efficient way, with reduced cost, of incorporating air and reducing slabs specific mass, leading to a reduction of acoustic transmission of impact sound in flooring systems; thus, it was proposed the use of polymeric waste as a building element;*
- *In the acoustic performance classification, the variation in samples height was the main variable of influence in the first mixes, prevailing in relation to waste use percentages. When using the fine aggregates replacement, EVA waste had a higher influence on slabs acoustic performance;*
- *Both phases of this study have indicated that lightweight aggregates are determinants in the reduction of measured impact sound values, being that all sets reached at least an intermediary performance according to ABNT NBR 15575:2013 classification. When comparing values obtained in lightweight subfloor slabs to those of the analyzed conventional slab, all sets presented noise decrease, allowing for more comfort in rooms.*

In the experimental phase, it was realized that thickness variation is not linear with the increase in impact sound acoustic insulation. Variation took place with a stronger influence of the smaller grain size of the EVA waste aggregate.

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