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Research of recycled mortars behaviour towards impact noise

Estudio del comportamiento de los morteros reciclados frente al ruido de impacto

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ABSTRACT

Currently there is a wide range of systems and materials that are used as impact noise absorbers, offering good performance avoiding the transmission of vibration through the forgings. In this research, four centimeters thick sheets of mortar were fabricated using four types of different aggregates combined with different typologies of insulation. Taking advantage of the minor density of mortars elaborated with recycled aggregates, it was proposed to substitute 100% of natural aggregates with recycled aggregates in order to fabricate mortars used in floating slab systems, as they offer more efficient solution from the acoustic point of view. The mortars elaborated with ceramic and mixed recycled aggregate presents the best solution to mitigate impacts produced on the surface reducing up to 20% of speed of impact transmission compared to mortars elaborated with natural aggregates.

Keywords: mortar, propagation speed, vibration transmission, recycled aggregate.

RESUMEN

En la actualidad existe una amplia gama de sistemas y materiales que se emplean como atenuadores del ruido de impacto, ofreciendo buenas prestaciones a la hora de evitar la transmisión de vibraciones a través de los forjados. En este trabajo, se han elaborado placas de mortero de cuatro centímetros de espesor con cuatro tipos de árido diferentes combinados con distintas tipologías de aislamiento. Aprovechando la menor densidad de los morteros elaborados con árido reciclado, se ha llevado a cabo una investigación en la que se propone sustituir el 100% del árido natural por árido reciclado para la fabricación de morteros empleados en el sistema de losa flotante, ya que ofrecen una solución más eficiente desde el punto de vista acústico. Los morteros elaborados con áridos reciclados de cerámica y mixto los que presentan la solución óptima para atenuar impactos producidos sobre la superficie, reduciendo hasta en un 20% la velocidad de transmisión de impactos frente a sus homólogos elaborados con árido natural.

Palabras clave: *mortero, velocidad de propagación, transmisión de vibraciones, árido reclicado.*

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1. INTRODUCTION

The impacts on the surface of any construction element produce an acoustic component called impact noise, able to be perceived even at great distances from the emitting source due to its ease of spread through the building structure (1).

Some researchers performed their investigations trying to develop construction systems able to reduce impact sound transmission using floating slabs able to decouple floor with forging (2),(3),(4), or using springs or other elastic materials able to absorb great part of energy produced by the impact and mitigate in this way its transmission (5),(6). Currently, the regulation in charge of study and control of acoustic quality inside buildings in Spain is the Technical Building code (7) that indicates design guidelines and good construction practices to avoid propagation of impact noise. There are different applications of vibrations produced by impact that can be used to measure physical properties of studied materials; this is the case of studies that try to determine resonance frequency of material (8), to measure dynamic elasticity module (9),(10) or to study degree of compaction of binders after vibrating during building process (11).

Nevertheless, independently on the final application of the research, the form of test performing gets special relevance while obtaining precise results at economical prices (12). Within the researched in this field, there can be differentiated on one side those that are focused on the improvement of one particular component of measuring equipment: hitting mechanism, frequency amplifier, used software, etc. (13),(14),(15) and on the other side there are investigations centered in improving methodology of tests trying to create new practices that allow obtaining higher performance and better results using current equipment (16),(17).

Furthermore, great consumption of recourses in the construction field has encouraged research of new recycling processes that could reduce environmental impact and offer similar performance to those of traditional materials (18).

In this contest, the use of construction and demolition waste (CDW) experienced a great development during the last years, as in Europe about 900 millions of tones are produced per year, a quantity that corresponds to about 30% of generated waste (19).

To elaborate mortars the use of recycled aggregates (RA) coming from this type of CDW recycling plants has been increased. In general, aggregates of three different typologies can be obtained: concrete RA, ceramic RA and mixed aggregated from the first two types (20). Among the properties of mortars fabricated with these aggregates lower density can be underscored compared to traditional mortars, among other factors due to the amount of waste contained in the aggregate and due to the lower compactness of the mortar (21). There are various authors who studied the importance of implementation of these aggregates into the process of masonry mortar fabrication, together with their advantages and disadvantages using natural aggregates (NA) (22),(23).

The objective of this research is to check whether the incorporation of these recycled mortars into the process of implementation of floating slab systems improves acoustic insulation against impact noise. Working with different percentages of substitution of NA until finding significant differences in the properties of both aggregates, mortar sheets were elaborated with an aim to measure their acoustic behaviour using measuring equipment of our own design, studying the speed of propagation through the material and the influence of support geometry on insulators used to create floating slab systems.

2. MATERIALS

Basic materials that are used in masonry mortars fabrication such as cement, aggregate, water and additive were used in the development of this investigation. Moreover, insulating sheets of expanded polystyrene (EPS) with different geometries were used to determine their influence on impact noise mitigation.

2.1. Cement

CEM II B/L – 32.5 N cement was used as this is the most commonly used in masonry mortars fabrication binder. UNE-EN 197-1: 2011 standard (24) and the RC-08 cement receipt instruction (25) the properties of this type of binders. Their characteristics are shown in Table 1.

2.2. Aggregates

To fabricate the reference mixes NA provided by Cemex company were used. Recycled mortars were elaborated using three different types of RA: concrete RA, mixed RA and ceramic RA coming from integral waste treatment plants “Molar”, “Salmedina” and “Tec-Rec” respectively situated in the Community of Madrid. The aggregates were sieved in the laboratory in order to eliminate fine fraction due to its poorer properties, until obtaining a fine fraction of aggregates passing through 4mm sieve and retained in 0.063 mm sieve (4/0.063 mm).

2.3. Additive

Because of high absorption of RA compared with NA, recycled mortars were elaborated using Glenium Sky 604 additive to obtain a plastic consistency without incrementing the excess of mix water. The additive was provided and prescribed by the technical department of BASF Company.

Table 1. Characteristics of CEM II B/L – 32.5 N

Physical Characteristics										
Density (g/cm³)		*Specific surface (g/cm²)*					*Intial set (min)*			*Final set (min)*
3.03		4000					175			275
Chemical composition determined through X ray fluorescence										
Al_2O_3	*CaO*	*Fe_2O_3*	*K_2O*	*MgO*	*SiO_2*	*TiO_2*	*MnO*	*P_2O_5*	*NaO_2*	*Loss on ignition*
3.25	60.10	2.56	0.26	1.75	18.13	0.14	0.02	0.16	0.22	11.85

2.4. Insulating

To separate floor sheets and to study the impact of interposition of acoustic insulator under different geometries between two surfaces, elastic supports of expanded polystyrene (EPS) of low density (10 kg/dm^3) were designed using software FreeCAD 0.16 (26). Afterwards and due to its difficult manual execution, it was decided to automate cutting process through numeric control. These insulators are evenly distributed over the entire inferior surface of sheets, producing in this way an effect of floatability that mitigates impacts provoked by hitting upper side of slabs. Characteristics of different geometries of EPS used in this research are shown in Table 2 and can be observed in Figure 1.

3. METHODOLOGY

According to the percentage of used RA, to perform the tests different dosages in the elaboration of mortars and a measurement equipment of our own design were used.

3.1. Dosages

Experimental program was developed using CEM II/B-L 32.5 N binder. To elaborate recycled mortars three percentages of substitution of NA were used: 50%, 75% y 100%, of each one of three types of used RA, with a relation 1:4 between both compounds (cement to aggregate in conditions of dry weight).

Fabrication of each of the mixes was performed using planetary mixer of CIB-701model of Ibertest brand, following the recommendation of the UNE-EN 196-1 standard (27). The amount of water used for mortars elaboration was needed to obtain plastic consistency according to the standard UNE-EN 1015-3 (28), that is to say, runoff value of 175±10 mm. Mixes fabricated with RA contained 1% of additive over the weight of cement.

The description of mortars used in the tests is performed following the nomenclature:

$$M - A - T - X$$

where M indicates that this is cement mortar, A is the type of aggregate that can be NA in case of NA or RA in case of RA, T is the type of RA, that can be C for concrete RA, M in case of mixed RA and Ce in case of ceramic RA. Finally, X indicates the percentage of substitution of RA 50%, 75% or 100%. Table 3 shows the dosages used in this research.

3.2. Experimental program

Experimental program was divided into three parts. The first part was dedicated to the characterization of different aggregates used for mortars elaboration. During the second part the tests of bulk and real density, compactness and flexural strength were performed for different mortar mixes elaborated with both natural and RA. In order to determine the

Table 2. Geometric characteristics of EPS sheets.

Type of sheet	Dimensions EPS (cm)	Plugs characteristics		
		Number	Dimensions (cm)	Placement
A	50 x 50 x 4⁽¹⁾	49	2.5 x 2.5 x 2	Separated 5.25 cm not joined
B		25	2.5 x 2.5 x 2	Separated 9 cm joined in a row
C		25	7 x 7 x 2	Separated 3.5 cm joined in a row
D		49	7 x 7 x 2	Not separated

(1) The height includes 2 cm of a sheet and 2 cm of plugs height.

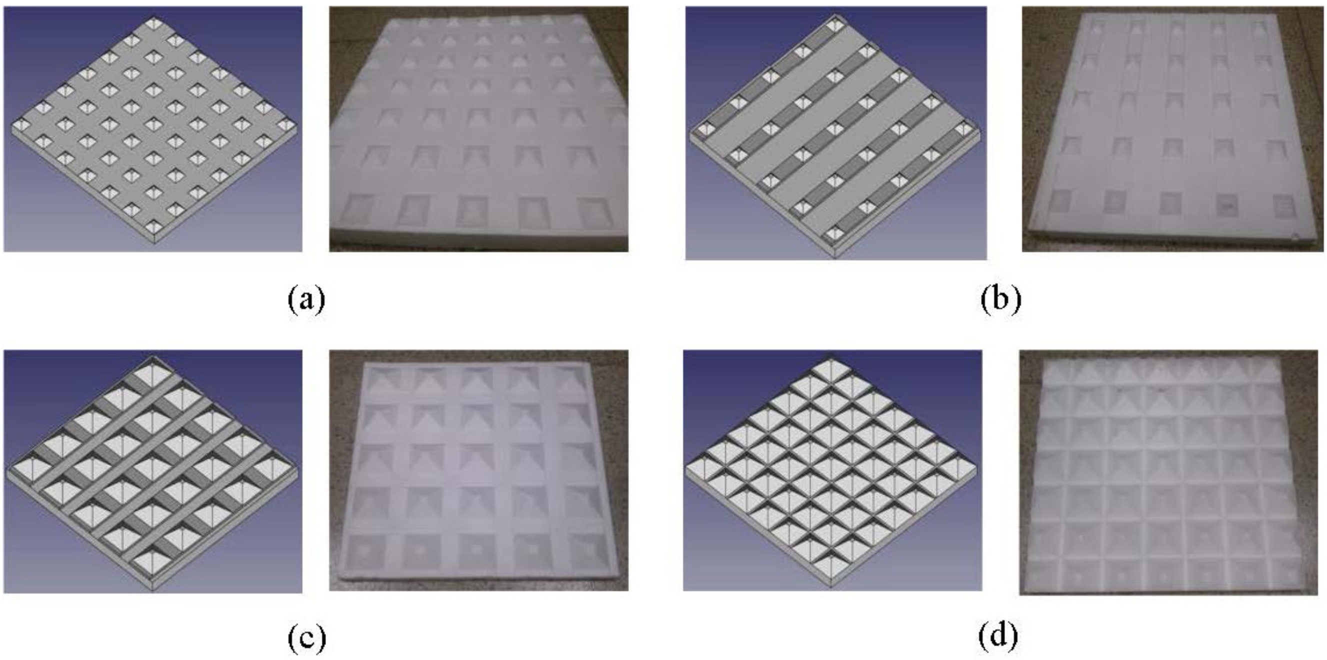

Figura 1. Insulating EPS supports of different geometries.

Table 3. Dosages.

Mix		Mix proportions		
	RA %	Cement	Aggregate	Water
M-NA	–	1	4	0.58
M-RA	50	1	4	0.75
M-RA	75	1	4	0.86
M-RA	100	1	4	0.89

Note: same water amount for all RA.

existence or no existence of significant differences in the behaviour of mortars made with different percentages of substitution of RA, a statistical analysis using ANOVA table was performed. For all the ANOVA performed in this research it was verified that the residuals complies with three conditions: independence, normality and homoscedasticity. The design of experiment carried out in this part of research is based on the factors and levels shown in Table 4.

Finally, once the results were analyzed, those dosages that after statistical study presented significant improvement were chosen to carry out the test of impact noise and to study the influence of the composition of mortar and the geometry of insulators on the speed of propagation of vibrations through the elaborated sheets.

As it can be seen in Figure 2, unlike the standardized equipment proposed by the UNE-EN ISO 10140-5:2011 standard (29), this research used an alternative equipment based on a round-shaped metallic level hammer with 15 mm radius and a sphericity over 500 mm, that allow obtaining the unique even impact in all the tests in the way that the energy introduced into the system was always the same.

Table 4. ANOVA table design.

Factors	Levels
RA type	Concrete RA (C), Mixed RA (M) and Ceramic RA (Ce)
Substitution (%)	50% (1), 75% (2) and 100% (3)

Transducer able to measure vibrations produced in buildings was used to perform the measurements. It is formed by the triaxial accelerometer CESVA© able to detect impacts of very low frequency, and by the vibrometer of VC431 model that allows obtaining in real time a response in terms of speed of propagation of vibration. Moreover, it can be connected to a computer in order to save the collected data of taken measures.

4. RESULTS AND DISCUSSION

4.1. Characterization of aggregates

Characterization of aggregates used in this research was performed following the requirements established by the UNE-EN 13139 (30) standard. Tests of physical characterization give the following results shown in Table 5.

As it can be seen in Table 5 main characteristics of RA compared to NA are lower density, higher friability coefficient, and higher water absorption. These characteristics are crucial both for physical characteristics of mortars and their mechanic behaviour and are caused mainly by the amount of adhered mortar in RA as found in other researches (31),(32).

In terms of relative and bulk density, RA of ceramic and mixed type are those which present significantly lower value compared to concrete RA, as it can be seen in multiple range test shown in Tables 6 and 7.

In terms of chemical requirements which RA have to comply with to be used in mortar fabrication, chlorides and sulphurs content tests were carried out following the UNE-EN 1744-1 (33) standard. As it can be observed in Table 8, the content

Table 6. Multiple range test corresponding to bulk density of recycled aggregates.

RA type	Count	Mean	Homogeneous Groups
RA – C	12	1299.42	X
RA – M	12	1231.50	X
RA – Ce	12	1241.58	X

Table 5. Physical characterization of aggregates

Test	Fine Content (%)	Fineness modulus (%)	Friability (%)	Bulk. dens, (Kg/m³)	Dry dens. (Kg/m³)	Water Absorption (%)
Standard	UNE EN 933-1	UNE-EN 13139	UNE-EN 83115	UNE-EN 1097-3	UNE-EN 1097-6	UNE-EN 1097-6
RA – C	4.13	4.72	24.84	1299	2217	6.10
RA – M	5.04	4.93	26.04	1232	2143	6.61
RA – Ce	4.53	4.27	26.54	1242	2147	8.02
NA	2.52	4.25	22.45	1565	2415	0.92

* Total amount of 12 independent of each type of RA as tested.

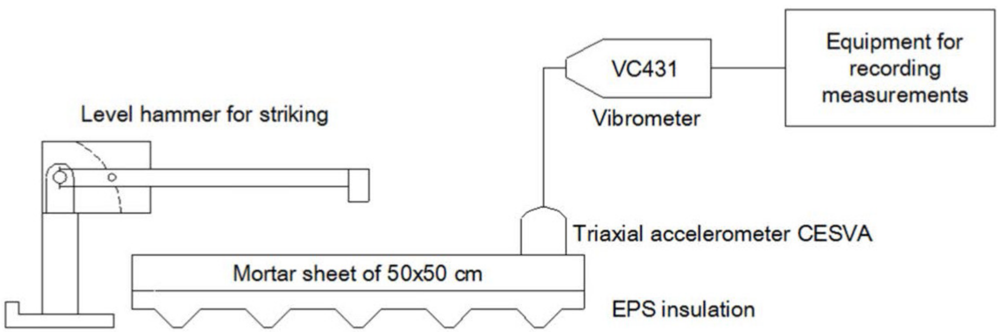

Figura 2. Measuring equipment.

Table 7. Multiple range test corresponding to real density of recycled aggregates.

RA type	Count	Mean	Homogeneous Groups
RA – C	12	2216.50	X
RA – M	12	2142.92	X
RA – Ce	12	2146.92	X

Table 8. Content of chlorides and total sulphur.

RA type	Chlorides	Total sulphur
RA – C	0.0030	0.67
RA – M	0.0037	0.86
RA – Ce	0.0039	0.87

* Total amount of 12 independent of each type of RA as tested.

of chlorides soluble in water does not overcome the limit established by the standard UNE-EN 998-2 (34) of 0.06%. Furthermore, the content of total sulphur never overcomes the limit if 1% established by the standard UNE-EN 13139 (30).

According to the obtained results, three types of RA used in the research comply with the requirements established by the reference standards for their use as a raw material in masonry mortar elaboration.

4.2. Physical properties of mortars

Firstly, the tests of bulk density, real density and compactness of mortar fabricated according to the standard UNE-EN 1015-10 (35) were carried out. The results are shown in Table 9.

Generally, bulk and real density in hardened state are lower in RA compared to the reference mortars. When the amount of used RA increases, both densities decrease and the compactness obtained as quotient between both decreases. This decreases mechanical properties of recycled mortars due to their high porosity.

According to the statistical analysis (Tables 10 and 11) it can be seen that type of used RA and substitution percentage are significant factors having < 0.05 p-value in bulk and real density. Due to the fact that factor of the substitution percentage is significant, it can be concluded that recycled mortars elaborated with 100% of any type of RA have significantly lower bulk and real density than mortars elaborated with different substitution percentage.

In terms of multiple range tests, both in case of dry density and real density, there are no significant differences between mortars made with concrete RA and mixed RA. However, mixes elaborated with ceramic RA show significantly lower

Table 9. Density and compactness of mortars

Dosage	Bulk density (kg/dm³)	Real density (kg/dm³)	Compactness (%)
M – NA	1980	2270	87.22
M – RA – C – 50%	1830	2230	82.06
M – RA – C – 75%	1800	2170	82.95
M – RA – C – 100%	1760	2127	82.75
M – RA – M – 50%	1830	2220	82.43
M – RA – M – 75%	1800	2175	82.76
M – RA – M – 100%	1760	2150	81.86
M – RA – Ce – 50%	1800	2150	83.72
M – RA – Ce – 75%	1779	2120	83.92
M – RA – Ce – 100%	1730	2120	81.60

Table 10. Analysis of variance for Bulk Density – Type III Sums of Squares.

Source	Sums of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A: RA Type	1458.0	2	729.0	81.00	0.0006
B: (%) Substitution	7478.0	2	3739.0	415.44	0.0000
RESIDUAL	36.0	4	9.0		
TOTAL (CORRECTED)	8972.0	8			

Table 11. Analysis of variance for Dry Density – Type III Sums of Squares

Source	Sums of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A: RA Type	4790.89	2	2395.44	7.09	0.0484
B: (%) Substitution	7117.56	2	3558.78	10.53	0.0255
RESIDUAL	1351.78	4	337.944		
TOTAL (CORRECTED)	13260.2	8			

density. As an example, Table 12 shows multiple range test for bulk density.

To complete the characterization of RA and to evaluate other properties of mortars which have influence on the speed of propagation, flexural strength test was carried out. The results are shown in Figure 3.

For all the used dosages the decrease of flexural strength was observed when the amount of used RA increases, observing important decreases in mixes with 100% of RA as was expected. Comparing flexural strength of recycled mortars with one of mortars made with natural sand (4.36 MPa), the loss of flexural strength between 16% and 30% was observed depending on the quantity and the type of incorporated recycled aggregates.

ANOVA table for "flexural strength" variable shows that both factors are important and consequently have influence on this property. In multiple range tests it can be seen that there are significant differences only between the mixes made with concrete RA and mixes elaborated with other types of RA (Table 13).

After analyzing the results of the characterization of cement mortars, the test of impact vibrations transmission was carried out only for the mixes that incorporate 100% of three types of RA because of their significantly lower density as shown in performed ANOVA table.

4.3. Impact vibrations transmission

Transmission of impact vibrations produced by the hitting equipment over the surface of elaborated sheets and quantified in terms of speed of propagation is shown in Table 14, where are shown the results obtained measuring each of four corners of sheets, using or not four geometries of EPS insulation in order to determine the influence on the impact mitigation (Figure 4).

To analyze the results of this part of the research, ANOVA table was performed. The factors were the type of RA used for mortar elaboration and four types of insulation described in section 2.4. In case of RA the corresponding levels of this factor are: NA, RA-C, RA-M and RA-Ce and in case of insulation types there are five levels: insulation 1(A), insulation 2 (B), insulation 3(C), insulation 4(D) and without insulation (NI). The results of ANOVA table are shown in Table 15.

As it can be seen in Table 15, both factors taken into consideration are important for the proposed variable "propagation speed" as its p-value is less than 0.05. Another multiple range

Table 12. Multiple range test for Bulk Density by RA type.

RA type	Count	LS Mean	LS Sigma	Homogeneous Groups
Ce	3	1769.67	1.73205	X
M	3	1769.67	1.73205	X
C	3	1769.67	1.73205	X

* Method: 95.0 percent LSD

Table 13. Multiple range test for Flexural strength by RA type.

RA type	Count	Least Squares Mean	Least Squares Sigma	Homogeneus Groups
Ce	3	3,30333	0,0438854	X
M	3	3,30667	0,0438854	X
C	3	3,53333	0,0438854	X

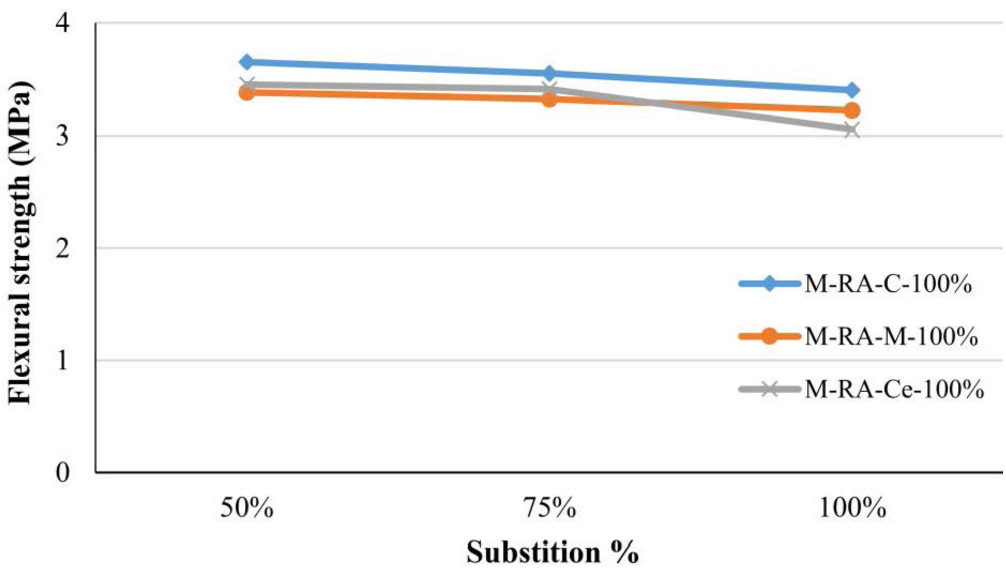

Figura 3. Flexural strength test for different aggregates and substitution rates.

Table 14. Speed of propagation measurement test.

Insulation Type	Speed of propagation (m/s)			
	M – NA	**M – RA – C – 100%**	**M – RA –M – 100%**	**M – RA – Ce – 100%**
Without Insulation	404.5	349.1	316.1	310.3
Type A	374.0	326.2	294.7	292.4
Type B	368.0	306.3	289.4	285.7
Type C	363.5	311.1	291.2	283.2
Type D	338.8	297.0	281.5	273.4

Table 15. Analysis of variance for Propagation Speed.

Source	Sums of Squares	*Df*	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A: RA Type	20290.4	3	6763.48	190.61	0.0000
B: Insulation	4891.86	4	1222.96	34.47	0.0000
RESIDUAL	425.795	12	35.4829		
TOTAL (CORRECTED)	25608.1	19			

test was also carried out to determine at which levels there are differences within the analyzed factors (Tables 16 and 17).

Observing Table 16 it can be concluded that there are significant differences in terms of propagation speed, and in case of RA propagation speed is lower. Among different types of RA significant differences were obtained, being concrete RA one that presents the highest propagation speed compared to mixed and ceramic RA between which no significant differences were observed.

Regarding the type of insulating, Table 17 shows that the use of insulation in mortar sheets reduces significantly the propagation speed through the material. Analyzing different insulations, four different homogenous groups were observed, where insulation of type D presents better behavior compared to others types.

Vibrometer VC431 described in part 3.2 was used to obtain the levels of acoustic insulation of the mortars in dB using different types of insulation. The results are shown in Table 18.

Table 16. Multiple range test for Propagation speed by RA type.

RA type	Count	Least Squares Mean	Least Squares Sigma	Homogeneus Groups
RA – Ce	5	289.00	2.66394	X
RA – M	5	294.58	2.66394	X
RA – C	5	317.94	2.66394	X
NA	5	369.66	2.66394	X

* Method: 95,0 percent LSD.

Table 17. Multiple range test for Propagation Speed by Insulation.

RA type	Count	Least Squares Mean	Least Squares Sigma	Homogeneous Groups
D	4	297.675	2.07838	X
C	4	312.125	2.07838	X
B	4	312.350	2.07838	X
A	4	321.825	2.07838	X
NI	4	345.000	2.07838	X

* Method: 95.0 percent LSD.

Table 18. Improvement of acoustic insulation of mortars with different insulators.

Insulation Type	Acoustic level reduction *(dB)*			
	M – NA	**M – RA – C – 100%**	**M – RA –M – 100%**	**M – RA – Ce – 100%**
Type A	7	20	29	30
Type B	9	25	31	32
Type C	10	24	30	32
Type D	16	28	33	36

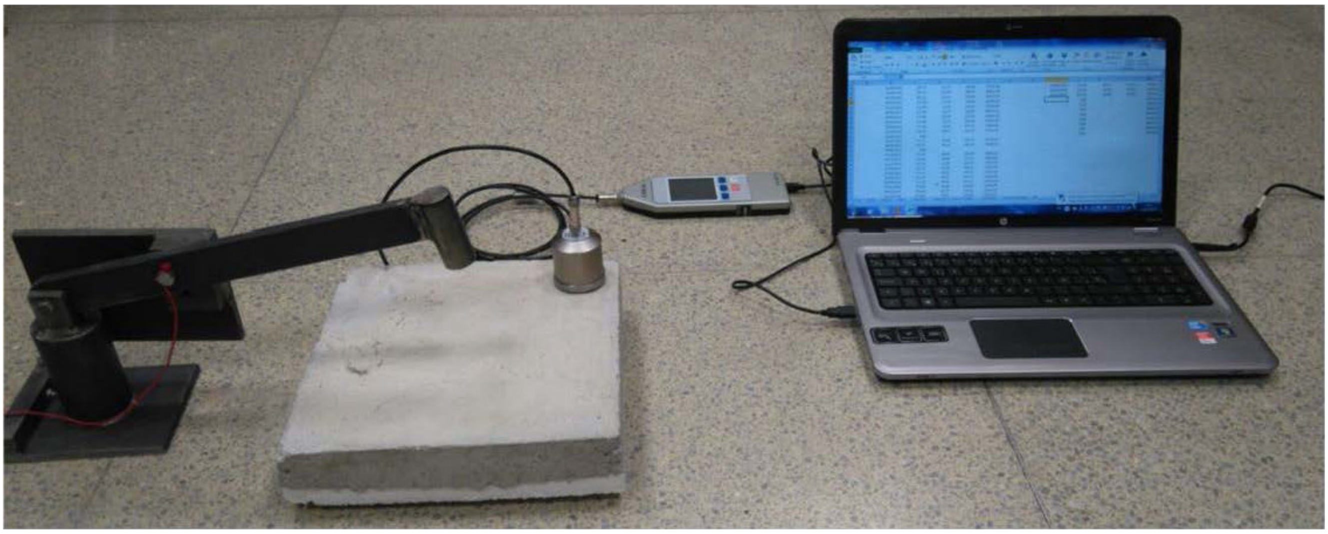

Figura 4. Measuring equipment.

Therefore, both the use of RA in the elaboration of mortars and the incorporation of insulation into the material improve the behaviour towards impact noise, as they decrease significantly the propagation speed of wave through the material. The mortars elaborated with 100% of mixed and ceramic RA in combination with type D insulation are studied typologies that have a better behaviour towards impact noise, reducing to 20% the speed of propagation through the material with regard to mortars fabricated with natural aggregates, which means an improvement of insulation of 20 dB as can be seen in Table 18.

5. CONCLUSIONS

This paper analyses the possibility to incorporate recycled aggregate to cement mortars for its use in floating slab systems. To that end, three types of RA marketed in Spain were used as a substitution for natural aggregate in different proportions. Moreover, hitting equipment of authors' own design and four different geometries of EPS insulation were used to find a constructive solution that would offer better performance in its use as a floating slab system. The main conclusions that arise from this study are given below:

After performing the tests it could be observed that mortars elaborated with RA have lower density compared to mortars elaborated with NA. Within these differences, both bulk and real density of concrete RA are higher than that of mixed and ceramic RA, as these last two types of RA present no differences between each other. These differences in densities have effect on flexural strength of mortars made with RA, being mortars made with concrete RA ones that have higher strength, being always lower than that of traditional mortars.

Furthermore, propagation speed through different mortars is related to the performed theoretical predictions, being mortars fabricated with mixed and ceramic RA ones that offer an optimum solution for constructive solutions implementations of floating slab, as they decrease significantly the propagation speed of vibrations through their surface. Moreover, it could be observed that the geometry of support also effects propagation speed, being insulators with supportive plugs of bigger surface ones (Type D) that offer more significant improvement in terms of acoustic insulation. Therefore, the geometry of type D in combination with mortars elaborated with 100% of substitution of ceramic and mixed recycled aggregate, decreases to 20% the speed of propagation of waves produced by the impact, with respect to mortars elaborated with natural aggregates, thus presenting better acoustic behavior, as it increases to 20 dB the level of acoustic insulation for the developed system of floating floor.

Apart from this decrease in the velocity of propagation, the incorporation of recycled aggregates in mortar fabrication as floating slab represents two advantages: on one side, it decreases the cost of this material due to the difference in the cost of natural aggregates and the cost of recycled aggregates (36), and on the other side, it allows the use of recycled materials as a raw material substituting exhaustible natural resources, contributing to more sustainable construction.

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