MECHANICAL AND ACUSTIC PROPERTIES OF CONCRETE MADE WITH RECYCLED AGGREGATES AND RECYCLED TIRE RUBBER

[1*]Rodríguez López, C.; [2]Parra Costa, C.; [1]Miñano Belmonte, I.; [1]Martinez Periago, S.; [1]Benito Saorin F.J.; [1]López Ayerra, J.; [3]Sánchez Martín, I.
[1]Centro Tecnológico de la Construcción Región de Murcia, Polg. Oeste, 30820, Alcantarilla, Spain
[2]Department of Architecture and Building Technology, Thecnical University of Cartagena, Paseo Alfonso XIII, 30203 Cartagena, Spain
[3]Department of Civil Engineering, University of Alicante, 03080, Alicante, Spain
e-mail: *crodriguez@ctcon-rm.com

ABSTRACT

Industrial progress used to be linked to the produce of large waste volumes. These industrial by-products are deposited in landfills despite these ones could be used to manufacture others. In fact, the construction industry could incorporate these materials to contributing to greater environmental balance.
This paper studies the manufactured of concrete using as aggregates two kind of different wastes: construction and demolition wastes as well as recycled tires rubber (NFU). Natural fine fraction is replaced by a 10% by volume of industrial products analyzed.
The mechanical behaviour and the acoustic properties of concrete made with recycled aggregates are studied. Results show a reduction in mechanical properties by using recycled aggregates and NFU. Nevertheless, it is observed that concrete made with fine recycled aggregate fraction of NFU could be employed with all the guarantees to produce concrete for non-structural applications.

Keywords: recycled aggregates, recycled tires rubber, concrete, shrinkage, material acoustic properties.

1.- Introduction

The use of recycling materials in building construction is a growing demand in today's world even if these materials come from other sectors, as is the case of used tires rubber (UTR). Recycling materials is a way to preserve the environment and natural resources for future. Recycling provides advantages such as reducing the amount of waste sent to landfill and recycling also is decreased the use of the world´s natural resources because this reduce the need of extraction more raw materials [1]. Many countries are reviewing their legislation in order to get a more sustainable future. In this context, the Spanish law R.D. 105/2008 [2] regulates the production and management of the Construction Waste Recycling (CWR). Their purpose is to achieve a sustainable development founding on prevention, reuse, recycling and revaluation.

The Spanish law prohibits the dumping of CWR with no previous treatment in order to promote recycling and enhance recycling waste arriving at the treatment plants. As for the tires discharge is regulated according to the European Directive 1999/31 / EC, which was established that as of July 16, 2003, no landfill is admissible whole used tires. Royal Decree 1619/2005 [3] provides for the proper management of the UTR and producer responsibility, making manufacturers and importers responsible for its management, once its useful life expires.

According to data collected in the II National Plan for Construction and Demolition Waste (II PNRCD) [4] included in the Integrated National Waste Plan (PNIR), which provides the current status of the CWR in our country, estimated waste in the year 2005 was 34,845,329 tons, and its recycling rate of around 15%. In the same year, the European Union produce about three million tons of UTR. Therefore, it is important to emphasize the importance of recycling and the revaluation of such waste.

Regarding the mechanical properties of concrete made with recycled aggregates the compressive strength tends to decrease when increase the proportion of recycled aggregates from construction or demolition waste, both for coarse or fine aggregates [5, 6-9, 10-13]. Strength losses are greater as the water/cement ratio are lower [6, 7], or higher-strength concrete category [9]. Concrete made with fine recycled aggregates reaches higher compressive strength than those made using coarse recycled aggregates, although compressive strength tends to be equal for higher percentages of substitution [9]. Other authors [8] found that replacing the 100% recycled fine fraction produce a loss of strength up to 18% lower than those obtained for 100% replacement of the coarse fraction. The total replacement of natural aggregates by recycling one could leads to an compressive strength a 24% lesser. This is due to the difficulties during compaction of the ceramic coarse aggregate. Use of the fine recycled aggregates is also proposed by others [14]. Nevertheless, other researchers found that concrete made replaced the fine aggregates by recycled aggregate were not successful [15, 16]. Because of these differences, the use of the fine fraction probably should not be ruled out in the future, although more research is needed.

The main objective of this work is to study concrete were fine aggregates is partially replaced by fine recycled aggregate from construction and demolition waste as well as study the use of rubber from used tires as fine aggregates (UTR).

2.- Experimental program

2.1.- Materials and mixtures

In order to study the influence of using recycled aggregates and rubber from used tired as fine aggregates six different mixed were made. Two series of concretes were made: the first one made with two sieves of aggregates using 0/3 and 5/12 (HT1),

and a second using only a fine fraction 0/3 (HT). Therefore, two reference concretes manufactured with only natural limestone aggregate: " 1.HT” and “1.HT1" (reference), and the remainder containing granular material from used tire " 2.HT1 Rubber and 2.HT rubber"; recycled aggregate from waste prefabricated concrete vaults" 3 .HT precast " and arid ceramic bricks recycled from" 4. HT Ceramic ".
Different type of reference concretes was made. One made with only limestone fine aggregates (0/3) “1.HT1 y 1.HT”, another made just with rubber from used tired “2.HT1Rubber y 2.HT Rubber”. The rest of mixed were made only with rubber from used tired “2.HT1Rubber y 2.HT Rubber”, aggregates from precast concrete vault “3 .HT Precast” and finally aggregates comes from clay brick “4. HT Ceramic”.
In figure 1 the particle sizes of aggregates used is indicated. All concretes were made using a CEM IIIa, with normal initial strength of 42.5 N/mm^2, according to the Spanish Instruction for Cement Reception RC-08, also in the case of HT1 contained a superplasticizer additive BASF "MasterGlenium 303SCC".

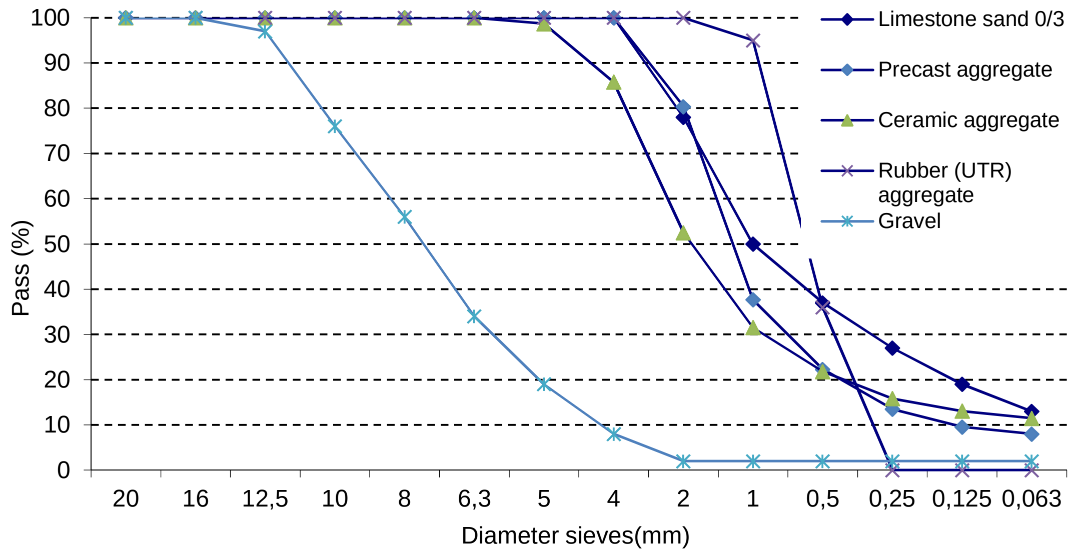

Fig. 1 “Grading curves of aggregate”. Source: the author

In order to study the influence of recycling materials on concrete porosity all mixtures were made with the same water/cement ratio because of the matrix porosity and interfacial transition zone depends mainly on the w/c ratio. The amount of recycled aggregates is fixed in a percentage of 10% (volume) of the total aggregates. The characteristics of each mixture are given in Table I.

Mixture	Cement (Kg/m^3)	Water (Kg/m^3)	superplasticizer (Kg/m^3)	Gravel (Kg/m^3)	Limestone sand (Kg/m^3)	Recycled aggregates		
						UTR (Kg/m^3)	Recycled concrete (Kg/m^3)	Ceramic (Kg/m^3)
1.HT1 (reference)	283,5	201	2,835	660,96	1423,9	0	0	0
2. HT1-Rubber	283,5	201	2,835	660,96	1215	84	0	0
1.HT (reference)	400	280	0	0	1800	0	0	0
2. HT-Rubber	400	280	0	0	1620	73	0	0
3. HT-Precat	400	280	0	0	1620	0	170	0
4. HT-Ceramic	400	280	0	0	1620	0	0	131

Table 1 “Mixtures proportions of concrete”. Source: the author

2.2.- Test methods

Fresh and hardened behaviour tests such as slump, compressive strength tests, modulus of elasticity, flexural strength as well as acoustic absorption coefficient tests were implemented.

- Slump test measures the workability of fresh concrete. This test is made according UNE EN 12350-2:2009. Part 2.
- The compressive strength, modulus of elasticity and flexural strength tests were all conducted according to the specifications given in European standards EN 12390-3:2009/AC: 2011, EN 12390-13:2014 and UNE-EN 12390-5:2009 respectively. Compressive strength and modulus of deformation was tested on cylindrical specimens with a diameter of 150 mm and a height of 150 mm. Flexural strength is tested on a square section prisms, 100 mm x 100 mm x 400 mm, manufactured according to UNE-EN 12390-1: 2009 and UNE-EN 12390-2: 2009. All the specimens were stored in a climate room at 20 ± 2ºC and at least 95% RH until they were tested at 60 days.
- Acoustic Absorption coefficient was measured using an impedance tube with a diameter of 3.45 cm and a frequency range of 500 to 5000 Hz according to the specifications given in European standards EN ISO 10534-2: 2002. Part 2. For every type of concrete two specimens with a thickness of 4 cm were made. The values given are the mean of two samples tested.

2.3.- Results and discussions

2.3.1.- Slump test

The slump test results are show in figures 2. When test slump is 0 – 20 mm the concrete is used for normal reinforced concrete placed with vibration. The results show a slump of 10 mm in the case of HT1 and HT1-Rubber. Mixtures 4.HT-Ceramic show a slump higher because the aggregates were previously saturated. Furthermore the use of NFU causes that part of the water is removed of mixture towards the perimeter and it made that concrete mixtures becomes drier.

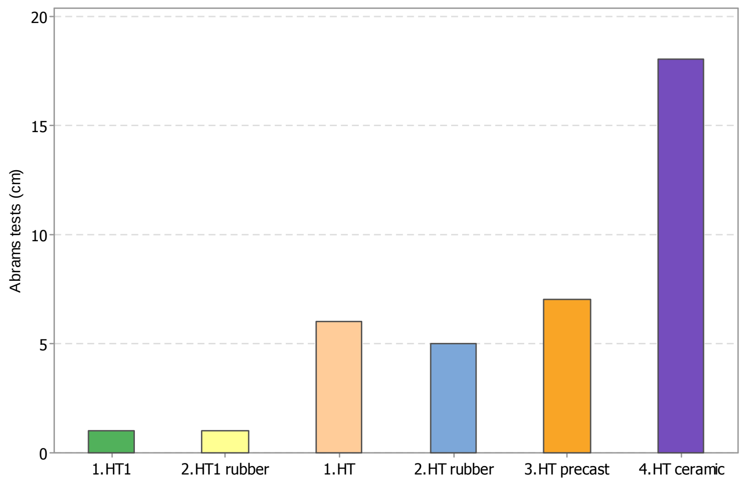

Fig. 2 “Abrams tests results measured in cm”. Source: the author

2.3.2.- Compressive and flexural strength

The results of compressive and flexural tests are shown in figures 3 and 4. It is observed that the reference mixtures "1. HT 1 and .HT" both made with natural limestone aggregate reach greater compressive and flexural strength.

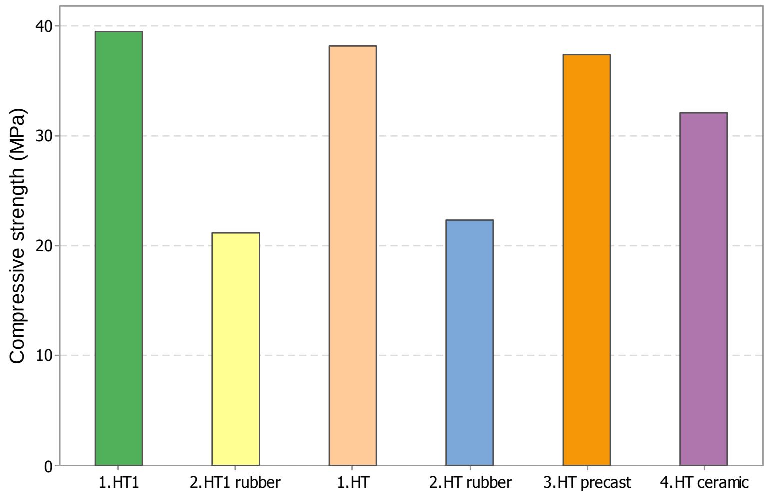

Fig 3. "Compressive strength 60 days (MPa)". Source: the author.

Compression strength of concrete made with recycled aggregates from crushed waste concrete vaults (3. HT Precast), is similar to the conventional concrete reference. This may be due to the higher water absorption of the cement paste when recycled aggregates are used so it decrease the effective ratio w / c of the mixture, and it is improved some mechanical properties, such as compressive strength. By other hand, concrete made with ceramic aggregates reach lower strength than that of conventional one. These mixtures show a compressive strength of a 15,9% lower than reference mixtures. Besides, the strength of the ceramic recycled aggregate is less than natural aggregate.

In the mixtures containing rubber as aggregate results show a resistance of about lesser up 18 MPa than reference concrete. This lesser strength may be due to difference of elastic behaviour between the cement paste and rubber. When the concrete is subjected to stresses, the rubber tends to deform more than cement paste, which causing internal stresses and even cracking in the rubber/paste interface [16].

The results of the average values of flexural strength are shown in figure 4. In concrete where the natural aggregate is replaced by recycled aggregate results show a lower strength than the reference concrete. In concretes made with rubber aggregates the results show even lower flexural strength reaching around 30% over the reference concrete.

That is to say, replacing fine aggregates by recycled aggregate or UTR leads to a lower compressive and flexural strength except in the mixture HT-Precast, where similar compressive strength is reached.

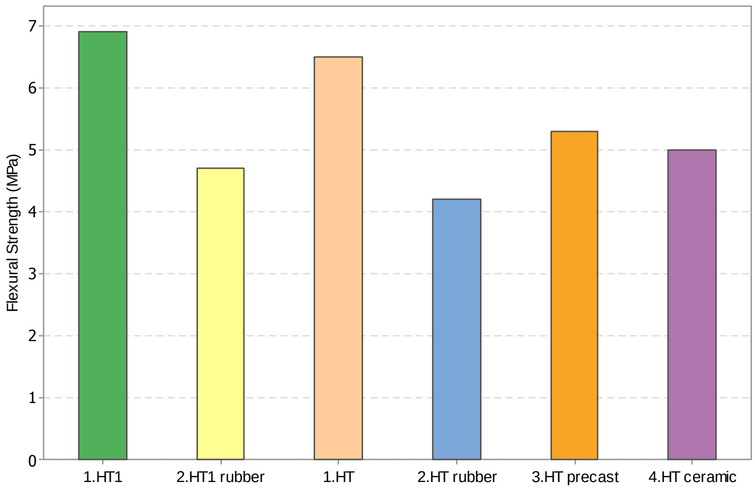

Fig. 4 “Flexural Strength”. Source: the autor.

2.3.3.- Modulus of elasticity

Results of the modulus of elasticity are shown in Fig. 5. It clearly shows that concrete made with recycled aggregate have a lower modulus of deformation than concrete pattern mixtures. However the average value of 3.HT-Precast is very similar to reference one.

Regarding the use of rubber as aggregate the results show that the modulus of elasticity is lower. Thus, modulus reaches values around 30% lesser than reference concrete. This is due to the lesser rubber rigidity than natural aggregates, so the rubber tends to deform more than cement paste.

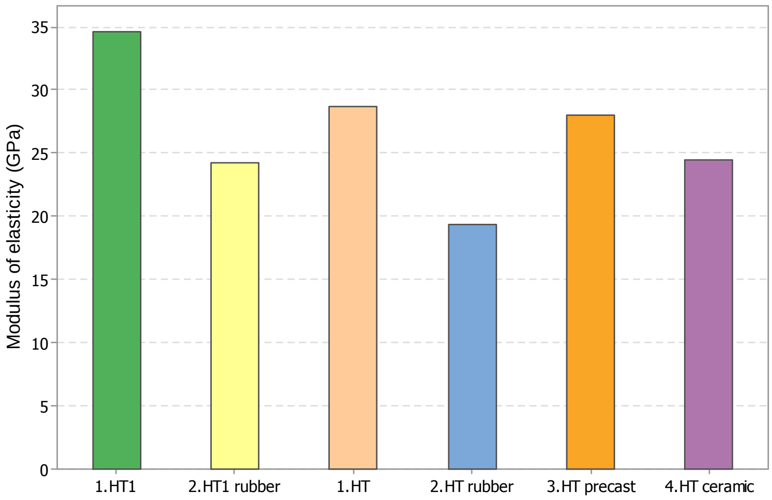

Fig. 5 “Modulus of elasticity (GPa)”. Source: the author.

2.3.4.- Acoustic absorption coefficient

The coefficient "α" is used as acoustic absorption parameter to assess the ability of concrete made to absorb sound. When a material fully absorbs the sound waves, the value of "α" is 1. However, material that does not absorb sound at all would have a "α" of 0. In general, conventional concrete has a value of "α "between 0.05 and 0.10 [17].

Figure 6 shows the absorption coefficient obtained for the frequency range studied. Among measures of the same type of concrete differences "α" of up to 0.08, so that the observed differences between types could not be considered significant were obtained. All concretes studied have similar absorption coefficient: 0.05 to 0.2 for the range 1000-5000 Hz.

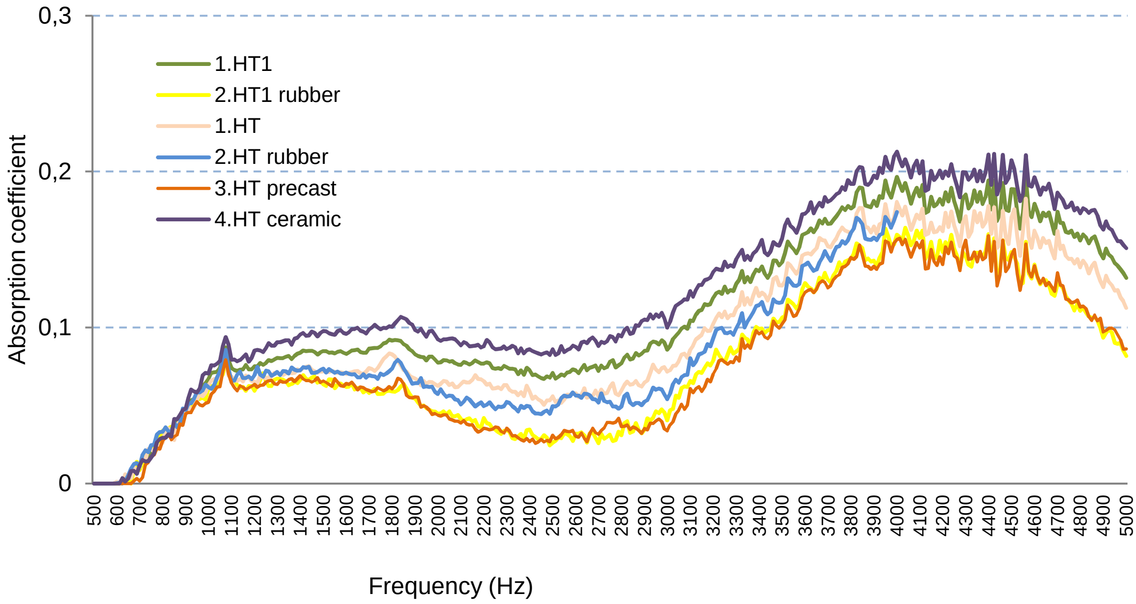

Fig. 6 “Absorption Coefficient”. Source: the author.

2.4.- Conclussions

The following conclusions can be drawn from the results and discussion of the experiments:

- Concrete made with recycled aggregate reaching a lower compressive strength. The modulus of elasticity tends to increase with increasing compression strength.
- Concrete where natural aggregates are replacement by recycled aggregate and used tire, show lesser flexural strength values of up to 30% compared to the reference concrete.
- Replacing 10% of recycled natural aggregate sand residues from prefabricated concrete vaults, does not modify the compressive strength.
- The acoustic absorption coefficient does not vary significantly by the use of recycled aggregates, reaching similar values to the reference concrete.

REFERENCES

[1] Rodriguez, C (2013). Estudio sobre la incorporación de áridos mixtos reciclados en prefabricados de hormigón vibrocomprimido no estructurales. Trabajo Final de Máster Ingeniería de los Materiales, el Agua y el Terreno. Universidad de Alicante. Alicante.

[2] Real Decreto 105/2008, de 1 de febrero, por el que se regula la producción y gestión de los residuos de construcción y demolición.

[3] Real Decreto 1619/2005, 30 de Diciembre (2005). Sobre la gestión de neumáticos fuera de uso.

[4] II Plan Nacional de Residuos de Construcción y Demolición 2008-2015 (II PNRCD). http://www.cepco.es/Uploads/docs/pnir_anexo_06.pdf

[5] Martínez-Lage I.; Martínez-Abella F.; Vázquez-Herrero C.; Pérez-Ordóñez J.L.(2012)3 Properties of plain concrete made with mixed recycled coarse aggregate. *Construction and Building Materials*, 37, 171-176.

[6] Chen H.; Yen T.; Chen K.H (2003). Use of building rubbles as recycled aggregates. Cement and Concrete Research, 33, 125-132.

[7] Mas B.; Cladera A.; Francisco Pitarch, T.O. (2012). Influence of the amount of mixed recycled aggregates on the properties of concrete for non-structural use. *Construction and Building Materials*, 27, 612-622.
[8] Lovato P.S.; Possan E.; Dal Molin D.C.C.; Masuero A.B. (2012). Modeling of mechanical properties and durability of recycled aggregate concretes. *Construction and Building Materials*, 26, 437–447.
[9] Mas B.; Cladera A.; Bestard J.; Muntaner D.; López C.E.; Piña S.; Prades J. (2012). Concrete with mixed recycled aggregates: Influence of the type of cement. *Construction and Building Materials*, 34, 430–441.
[10] X. ESPINAR (2009). Aportación a la Construcción sostenible: Prefabricados de hormigón con árido reciclado vibrocomprimidos. *Revista Demolición & reciclaje*, 46, 68-75.
[11] Ana de Guzmán Báez (2010). Estudio de las propiedades fundamentales de elementos prefabricados de hormigón no estructurales, con incorporación de áridos reciclados en su fracción gruesa y fina. Tesis de Máster Universidad Politécnica de Madrid 2010
[12] Sousa J.G.G.; Bauer E.; Sposto R.M.(2003) Empleo de residuos de la construcción civil como áridos reciclados. Producción de bloques de hormigón*. Materiales de Construcción*, 53, 271-272.
[13] Poon, C.S.; Kou S.C.; Wan H.W.; Etxeberria M. (2012). Properties of concrete prepared with low-grade recycled aggregates. *Construction and Building Materials*, 36, 881–889.
[14] Evangelista L.; De Brito J. (2007). Mechanical behavior of concrete made with fine recycled concrete aggregates. *Cement and Concrete Composites*, 29, 397–401.
[15] Asociación Científico Técnica del Hormigón Estructural, ACHE, Grupo de trabajo 2/5. Utilización del árido reciclado para la fabricación de hormigón estructural. Monografía 11, 2006.
[16] Gónzalez-Fonteboa B.; Martínez-Abella F. (2008). Concrete with aggregates from demolition waste and silica fume. *Material and mechanical properties. Build Environ,* 43, 429-37.
[17] Royano, V.; Valls, S.; Marilda, B.; Vazquez, E. (2011) Estudio de hormigones con adición de polvo de neumàticos fuera de uso (NFU). A: Jornada de Recerca i Innovació a l'Escola de Camins. "Jornada de Recerca i Innovació a l'Escola de Camins". Barcelona: Universitat Politècnica de Catalunya. Escola Tècnica Superior d'Enginyers de Camins Canals i Ports de Barcelona.
[18] Neithalath N, Weiss J, Olek J.(2006). Characterizing enhanced porosity concrete using electrical impedance to predict acoustic and hydraulic performance. *Cem Concr Res*; 36:2074–85.