INCREASING OF THERMAL INSULATION AND SUSTAINABILITY IN HOLLOW CONCRETE BLOCKS USING RECYCLED MATERIALS

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Abstract

A great portion of the current energy consumption is due to construction and building maintenance for housing purposes. This is the main reason because we need to maintain the objective of increasing energy saving by more efficient and sustainable ways. A promising approach to achieve this goal is by means of using recycled building materials with a good thermal behaviour. In this paper, successful results are shown in the introduction of rubber as a recycled material in mortar. Good thermal insulation properties of rubber as a concrete aggregate are showed in bibliography. Its use in the production of hollow concrete blocks can be one of the most promising applies. Therefore two objectives can be achieved: the increasing of the energy efficiency of buildings and the decreasing of the negative impact of the construction techniques in the environment.

Keywords: *recycled materials; non-structural concrete; hollow concrete blocks; mechanical properties; rubberised concrete; crumb rubber*

Resumen

Una gran parte del consumo energético actual es debido a la construcción y mantenimiento de los edificios destinados a vivienda. Por ello es necesario mantener el objetivo de lograr un mayor ahorro energético de la forma más eficiente y sostenible posible. Un enfoque prometedor para conseguir este objetivo es mediante la utilización de materiales de construcción sostenibles con un buen comportamiento térmico. En este artículo, se presentan los resultados logrados con éxito en la introducción de caucho como material reciclado en morteros. El caucho reciclado presenta un buen aislamiento térmico en la bibliografía en sustitución de áridos del hormigón. Su uso en la producción de bloques de hormigón perforados puede ser una de las más prometedoras aplicaciones. De esta manera se cumplen dos objetivos, el incremento en la eficiencia energética de los edificios y la reducción del impacto ambiental de las técnicas de edificación actuales.

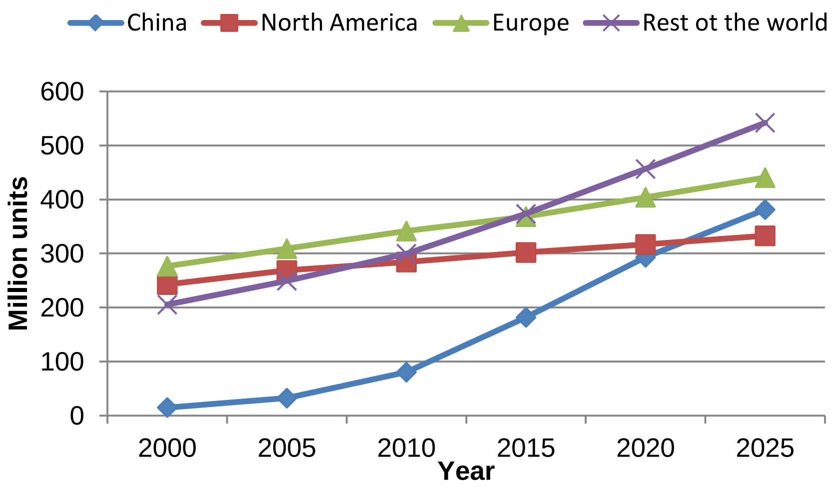
Palabras clave: *materiales reciclados; hormigón no estructural; ladrillos de hormigón perforados; propiedades mecánicas; hormigón aligerado con caucho; caucho reciclado*

1. Introduction

The increasing accumulation of waste tires has resulted in an important environmental problem. The difficulties to find a new reuse at the end of their life cause the accumulation in landfills and contamination of vast lands. The disposal of these wastes has become a severe health, social and environmental concern around the word. In like manner, currently putting forward initiatives that try to find novelty techniques for recycling are being driven.

According to European Tire & Rubber Industry (ETRA) (2011), 4.500 tons of tires were produced in Europe in 2010. The evolution of car and light commercial vehicle (LCV) park on the world major markets is shown in Figure 1. It is easy to establish an increasing tendency in the number of units produced in the world.

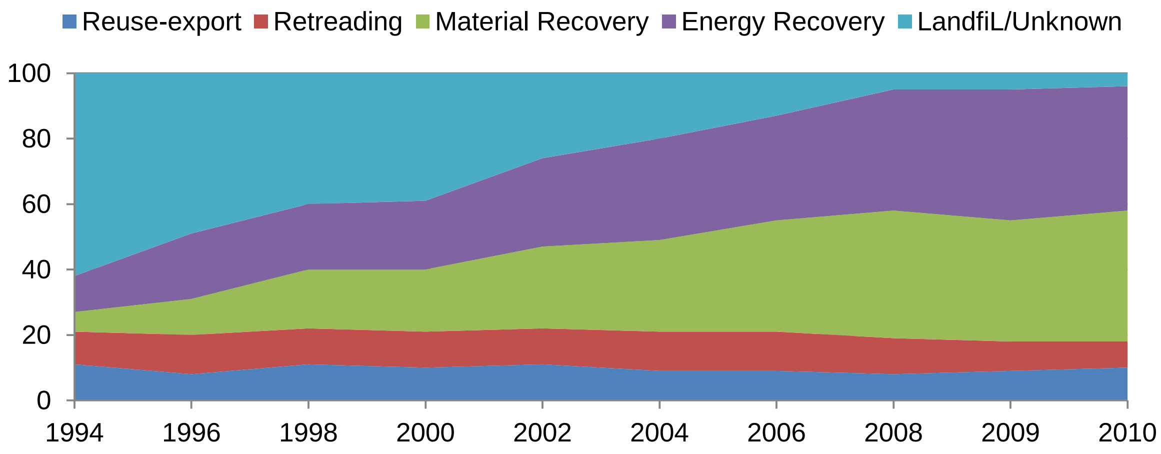
Figure 1: Evolution of car and LCV park word major markets



Source: ETRA (2011)

The used tires management trends in the European Union (EU) are shown in Figure 2. In 2010, it can be seen that the percentage of tires that were not treated were only the 4%. Despite this value only represents a low percentage of all the used tires in 2010, there is still a hide problematic situation with the storage of all the accumulated tires in the last decades.

Figure 2: Trends of EU management of Used Tires



Source: ETRA (2011)

Tires are mainly made of rubber and design to resist hard mechanical and meteorological conditions for long periods of time. Rubber, that is not easily biodegradable, needs more than 1000 years to have a complete degradation in nature. Tires are flexible and difficult to compress, these characteristics consequently do not contribute to a good disposing in landfills. This makes tires a hazardous waste material very difficult to recycle. However, rubber also shows a high heat capacity and a difficulty to be extinguished in fires; and for all these reasons, there is a necessity to recycle waste tires and utilize them in other potential applications. According to ETRA, the classification of the tire recovery routes in 2012 at the end of the tire life and its applications can be show in Table 1.

Table 1: Applications of reuse/recovery tires

	Application	Examples	%
Material recovery	Civil engineering and public works	Foundation of roads and railways; Embankment stabilizers; Draining material; Erosion barriers	18%
	Product applications	Flooring (playgrounds, sports fields) and paving blocks, roofing materials, wheels for caddies, steel mills & foundries, dock fenders	82%
Energy	Power Plants, co-incineration with other waste		8%
	Cement kilns		92%

Source: ETRA (2011)

In case of construction, one of the most competitive sectors in Europe, the production of its materials generates a high amount of energy waste. In addition to this, it is increasingly necessary to build with more sustainable materials. Mortar and concrete are two of the most widely used construction materials in the E.U. This is mainly due to their good durability, excellent compression strength and low cost production. However, the growing concern about the reserve of the natural resources and the high energy consumption on their production makes conventional mortar and concrete a non-environmentally-friendly product. For all these problems it is essential to find solutions with a lower environmental impact and cleaner production.

For many years, multiple studies have been carried out in order to determine the strategies of reuse construction materials from demolished buildings. The inclusion of recycled aggregates can contribute to a more sustainable construction. However a decreasing on the mechanical properties of the concrete is always observed. Depending on its use, a higher fraction of recycled aggregate can be included in non-structural concrete.

It is a fact that the use of rubber as a concrete aggregate can contribute to solve the problem of accumulation of waste tires. It can also decrease the negative impact of the construction techniques in nature. In the same manner, it is possible to achieve greater efficiency in the maintenance of buildings through their service life.

2. Related works

According to Najim and Hall (2010), waste rubber produced as a mortar and concrete aggregate is classified depending on its different particle size and geometry:

- Shredded or chipped rubber aggregate: chipped rubber has the biggest size of all the rubber aggregates used in concrete and mortar. It can be used as a partial substitute of coarse aggregate.

- Crumb rubber aggregate: it has a size between 4.75 and 0.425 mm. Almost every research study has used it as a partial replacement for natural sand.
- Ground tire rubber: this is the rubber aggregate passing through sieve No. 40 (0.425 mm). Few researchers have used this material in self compacting concrete, but it has been mainly used to modify asphalt properties and polymer modified bitumen.
- Fibre rubber aggregate: only a few researches have used shredded rubber in the form of a short fibre and long strips.

The mechanical properties of rubberised concrete usually vary depending on the size of the waste rubber particle added. In case of coarse aggregate, chip is actually the replacement more included in concrete. Other researchers prefer a mix design with both crumb rubber and chip. Crumb rubber is the main substitute of fine aggregate in the majority of studies. Topçu (1995) demonstrated that coarse rubber aggregates affect the properties more negatively than fine rubber aggregates.

Another important characteristic affecting the mechanical properties of concrete is the volume content that is substituted by rubber in the mix. In case of high percentage of rubber in the mix, mechanical properties of concrete decrease drastically. This affects specially to the compressive and flexural strength.

Non-structural concrete has different characteristic strength than concrete for structural purpose. Generally, the second one works under more strict conditions; according to Annex 18 of the Spanish Code on Structural Concrete EHE-08:

> *Concretes for non-structural use are defined as concretes that do not add structural responsibility to the construction but contribute to improve the durable conditions of the structural concrete or add the necessary volume of a resistant material to provide the geometry required for a certain purpose. (p. 517)*
>
> *Concretes for non-structural use are characterized by their low cement content and it is therefore advisable to use water-cement admixtures with the aim of reducing the porous structure of the concrete in its set state as far as possible. (p. 518)*
>
> *The minimum characteristics strength of these types of non-structural concretes shall be 15 N/mm^2. (p. 518)*

In case of non-structural concrete, less compressive strength is required and the quantity of rubber added as aggregate can be higher too. According to Batayneh, Marie *et al.* (2008) rubberized concrete is not recommended in structural elements where high strength is required, but it is useful for many other building elements like partition walls, road barriers, pavement, sidewalks, etc. Turgut and Yesilata (2008) also recommend its use as low cost lightweight building material, which may offer significant savings not only in labour and transportation, but also in the amounts of binder and steel reinforcement. Finally, Ling (2011) suggested that the rubber substitution used in concrete blocks should not exceed 10% volume for structural and 40% volume for non-structural applications.

Another important item is the compaction method of concrete when we are producing the specimens. There is a great difference between the compaction methods used at a prefabricated concrete industry and laboratory. Depending on the compaction force applied, a higher or lower compressive strength can be achieved. Works carried out by Ling (2012) show that the compressive strength of concrete blocks greatly depends on the compaction methods used. Regardless of crumb rubber content, the compressive strength of plant-made rubberized concrete paving blocks was higher than the corresponding manually-made.

It can also be observed variations on other physical properties. For example, an increasing on the thermal properties is detected as a result of implementing rubber in the mix. One potential use of building products made with rubberized concrete is the reduction of heat lost. Hernandez-Olivares and Barluenga (2004) had also concluded that it is also good the implementation of rubber in slabs to increase it resistance to fire and the explosive spalling. This could mean a reduction of the reinforcement covering in structural elements or an increase of safety in structural elements against fire.

Another material property that can be modified by including rubber in mortar is the acoustic insulation. These products have good properties acting as sound barrier. This is due to rubber is a less rigid material and can absorb better vibrations.

Other works have modified the surface of rubber aggregate to increase its adhesion to cement paste with promising results. Segre and Joekes (2000) used a NaOH treatment of the tire rubber particles to obtain a material suitable for engineering purposes where high strength is not necessary.

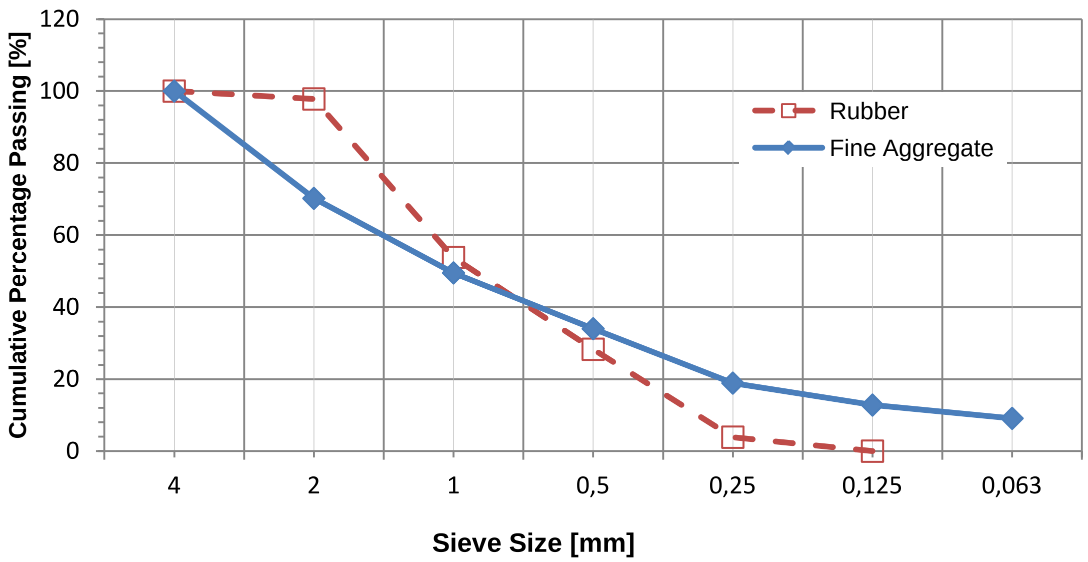
3. Materials

In this study materials consisted of Portland Cement Type II, fine sand and rubber aggregate. Tap water was used for all the mixes.

3.1. Rubber

Rubber aggregate used for all the samples was obtained from waste car tires without steel and textile fibbers. It was produced by mechanical shredding by Indugarbi NFU's, S.L (Navarra, Spain). Only one type of particle rubber was used, with a ranging size of 1-4 mm. According to the classification of rubber aggregates showed before, it can be classified as crumb rubber. Siddique and Naik (2004) give a similar definition for crumb rubber and consider this with a particles ranging in size from 4.75 (No. 4 Sieve) to less than 0.075 mm (No. 200 Sieve). The sieve analysis of crumb rubber and fine aggregate can be seen in Figure 3. The plot represents a comparative of the different percents of cumulative on each sieve between crumb rubber and fine aggregate. Rubber used has a density of 476.1 Kg/m^3 and it has been used as a partial substitute of sand, with a range of percentages of 10%, 15%, 20%, 25%, 30%, 35% and 40%. All the percent substitutions were calculated by volume of sand replaced. Residual particles with a particle size less than 1mm were sieve out before adding rubber to the mixture.

Figure 3: Comparative sieve analysis between crumb rubber and fine aggregate



3.2. Cement

Cement used in the research was Portland Type II (A-L 42, 5 R). It is specially recommended for light prefabricated pieces of concrete and the manufacturing of prepared mortars. It was produced by Cementos Portlad Valderrivas, S.A. (Navarra, Spain) and its chemical composition is given in Table 2.

Table 2: Composition of cement used

Composition	%
SiO_2	18.05
CaO	62.96
MgO	2.07
Al_2O_3	5.43
Fe_2O_3	1.53
SO_3	3.08
P.F	5.04
Total	98.16

3.3. Fine aggregate

Fine sand with a maximum particle size less than 4mm and a fineness modulus of 3.13 was used as fine aggregate. Fineness modulus was calculated according to UNE-EN 933-1 (1998).

3.4. Plasticizer

RheoFIT 786 provided by BASF L.S. was used as a plasticizer for semi-dry and prefabricated concretes. It was added and dissolved in the mixing water before being added into the mortar mix.

4. Mix design

In the mixing process sand aggregate and cement were placed dry in a concrete mixer and mixed for 1 minute. After that, crumb rubber was added and mixed for 1minute 30 s. When the rubber was uniformly scattered within all the mix, the plasticizer was added to the water. Then, water and plasticizer were slowly poured into the mix in two times of 1 minute each one.

After the mixing process, the finished fresh mortar was poured into plastic moulds. The addition of the mortar to the moulds was done in 3 uniform layers. Each layer was compacted before adding the following.

For each mix design four cubes of 100 x 100 x 100 mm were prepared for the 7-day compression strength test. A total of 50 specimens were produced, including control and rejected specimens. The water/cement ratio was 0.8 and kept constant for all the mixing process. The aggregate/cement ratio varied depending on the mix design. The details of the specimen's mix design are shown in Table 3 and Table 4.

Table 3: Proportions (by mass) of mortar for w/c ratio of 0.8

Control mix	Sand (g)	Rubber (g)	Cement (g)	Plastizer (g)	Water (g)	Total (g)
LN-80	8000	0	1000	5.81	800	9805.81
LN-80.10	7200	233	1000	5.81	800	9238.81
LN-80.15	6800	349	1000	5.81	800	8954.81
LN-80.20	6400	466	1000	5.81	800	8671.81
LN-80.25	6000	582	1000	5.81	800	8387.81
LN-80.30	5600	699	1000	5.81	800	8104.81
LN-80.35	5200	815	1000	5.81	800	7820.81
LN-80.40	4800	932	1000	5.81	800	7537.81

5. Curing

After mixing process, specimens were cured at room temperature of 20 ± 2 ºC with a humidity of 55% for the first day. After this day, the 1-day hardened specimens were demoulded and introduced in a cured tank at a temperature of 20 ± 1ºC for 4 days.

All the specimens were fabricated and cured according to the Spanish Standard UNE-EN 12390-2 (2009). The drying process occurs in laboratory during 3 days before the compression tests at room temperature.

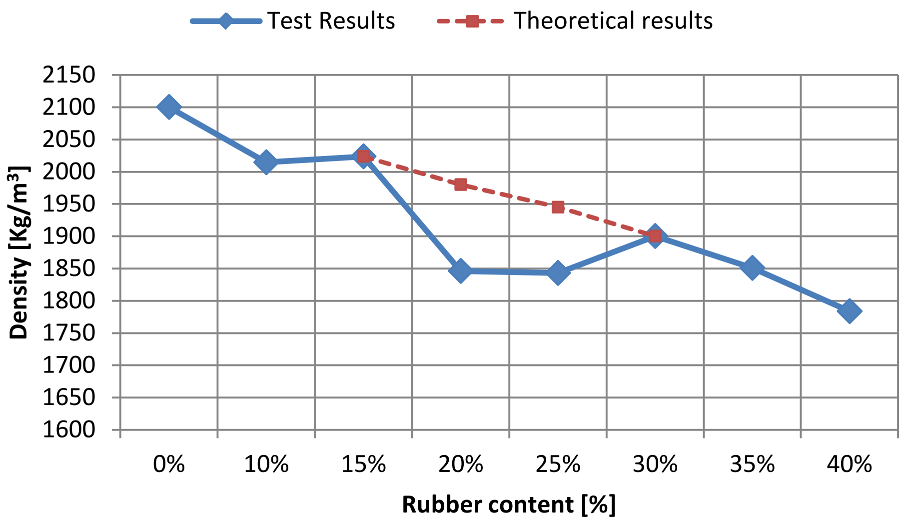
Table 4: aggregate/cement ratios and crumb rubber content for all the specimens

Control mix	Ratio aggregate/c	Crumb Rubber Content (%)
LN-80	8.00	0%
LN-80.10	7.43	10%
LN-80.15	7.15	15%
LN-80.20	6.87	20%
LN-80.25	6.58	25%
LN-80.30	6.30	30%
LN-80.35	6.02	35%
LN-80.40	5.73	40%

6. Density

Very low variations were observed in density and weight between the samples with the same composition. Rubber has lower density than sand. Due to the sand replacement by rubber is done by volume, density of mortar decrease when the rubber content increase. The correlation between density of the specimens and rubber content in the control mix can be seen in Figure 4. A linear tendency in the reduction of density strength can be seen, except for the 20% and 25% volume replacement of rubber.

Figure 4: Correlation between density and rubber content



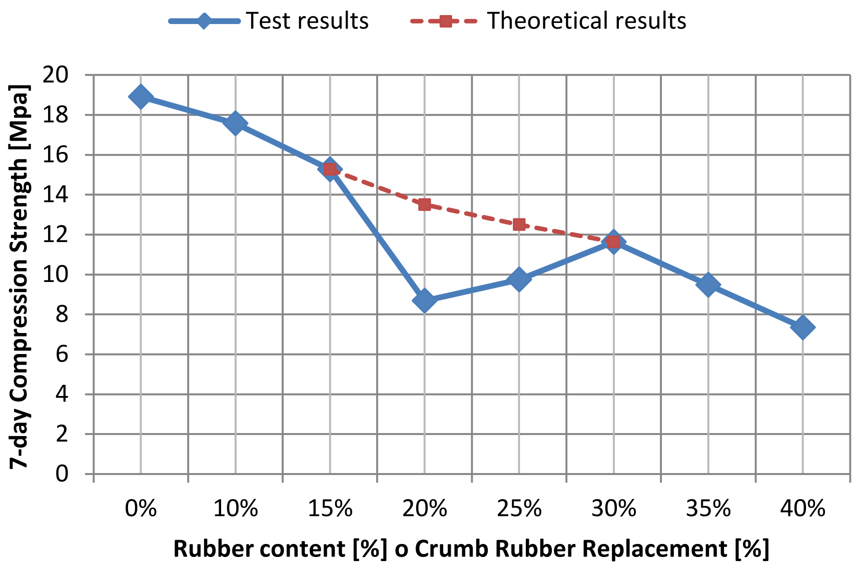
7. Test results of compressive strength

After curing process a compression test was applied to all the specimens. A Universal Testing Machine Servosis model ME-402/20 with a maximum load capacity of 250 kN was used to test all the samples. The compression tests were performed according to the Spanish Standard UNE-EN 12390-3 (2009) and the Spanish Standard UNE-EN 12390-4 (2001). An example of the specimens used for the compression test results can be seen in Figure 5.

Figure 5: Specimens used for the compression strength tests

Compression test results are shown in Figure 6. As expected, the 7-day compression strength decrease as the volume replacement of rubber increase. A linear tendency in the reduction of compression strength can be seen, except for the 20% and 25% volume replacement of rubber.

Figure 6: 7-day compression strength results



8. Discussion

Spanish EHE (2008) fixes the minimum characteristic strength for non-structural concrete in 15 N/mm^2. With the same mix design, the compression strength reached on a 28 days curing process would be higher than the results obtained for a 7 day curing process. In this work, according to the results of the 7-day compression strength test carried out, 15% of fine aggregate was the maximum volume replaced by crumb rubber. But it must be taken into account that there is a great difference between the compression strength of mortar cured at 7 and 28 days; thus authors believe that the possible percentage of crumb rubber included in the mixture can be higher.

Concerning the non-linear tendency of the test compression results at 20% and 25%, this issue can be explained by the low value of density of these specimens. If we observe the theoretical results of density and compression strength shown in Figures 4 and Figure 6, it seems like some mistakes in the mixing process can be the origin. For this reason, more specimens must be tested in future to validate or reject these results.

It is difficult to select only one reason that explains the decrease on some mechanical properties of mortar and concrete by adding rubber aggregate to the mixture. In our experiments, the decrease is specially pronounced in compression strength. The authors are completely agree with Mohammed, Hossain *et al.* (2012) that the decrease of the compressive strength is due to the physical properties of the rubber, which repels water during the mixing process and entrapping air on its surface. The entrapped air on the surface of crumb rubber particles causes an increase in air content in the concrete mixture and consequently produces a reduction in compressive strength. We also noticed that as higher percentage of rubber was included in mixture, as lower quantity of water was absorbed by the mortar. However, in opinion of Fattuhi and Clark (1996) and the authors the decrease in strength can be also due to rubber acting as voids that carries negligible load relative to the surrounding matrix and possibly increasing lateral strains and consequently causing early disruption of the matrix.

9. Conclusions

Test results showed that there is a great potential of use waste tires as rubber aggregate for mortar. Especially for those applications with a non-structural use that can be created with lower mechanical properties than concrete for structural purposes.

More research studies will be needed to confirm the good behaviour of rubberized mortar with curing times of 28 days and conclude the hypothesis of the reduction of the mechanical properties as a result of including rubber in the mixing process.

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