Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

Use of Rubber Particles from Recycled Tires as Concrete Aggregate for Engineering Applications

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ABSTRACT

This study explores the ameliorative effects of rubber particles on some properties of concrete. The used rubber scraps are obtained from a mechanical trituration process of post-used tires from motor vehicles and trucks. They have long been investigated for resource reutilization as an aggregate in concrete resulting in the 'Rubcrete mix', which can be conveniently used in various applications with promising effects. Rubcrete provides a final product with good mechanical properties and also represents an effective and inexpensive way of recycling the discarded tires. The aim of this work is to present the results of an experimental investigation conducted to identify the optimal types and quantities of aggregates in concrete mixtures for engineering applications. Some of the examined characteristics include: density of rubber aggregates, workability, air entrapment and compressive strength. Three types of rubber particles (ash rubber, crumb rubber and tire chips) have been used in the rubberized concrete mixtures replacing partially or totally natural aggregates.

INTRODUCTION

It was estimated that more than 250.000.000 post–consumption tires were accumulated annually in the 15 States of the European Union. In 1992, about 65% of the quantity produced in the then 12 member states was stored in dumps and only 35% underwent other regeneration methodologies. Ten years later, in 2002, the situation was completely overturned in the 15 member states. More than 65% of post-consumption tires were prepared for reuse/export, rebuilding, recycling and energy regeneration, whereas less than 35% was stored in dumps. Energetic and material product recycling represented the two principle types of regeneration and amounted to 44% of the total. With reference to actual codes (Dumps directive 199/31/EC), and despite the fact that the disposal in dumps of whole tires was forbidden since 2003 and that of lacerated tires since 2006, only 8 States adopted such directives. The practice of absorbing used tires in controlled dumps should be avoided because it creates another source of pollution. Tires represent a bulky refusal and require huge dump sites as more than 75% of a tire's volume is void. The presence of cavities and rubber elasticity also create mechanical instability with danger of fires in the stocked refuse mass. Furthermore, dumps can turn into a fertile habitat for the proliferation of rats and insects. To worsen matters, tires tend to re-emerge in time from the dump and micro–organisms may take more than 100 years to biodegrade them. The necessity to find alternative solutions to used tires is thus clear. Moreover, the increased consumption of concrete in building construction raised the problem of impoverishment of natural resources. Such considerations confirmed the necessity to individuate innovative technologies and alternative materials to improve not only the performance level of concrete but, and above all, to support the policy of environmental protection. It must also be remembered that most developing countries had to raise their awareness regarding the recycling of waste materials but have not yet developed effective standards and laws with regards the local reuse of waste materials.

Over the past few years, a number of researches have focused on the use of different shapes and sizes of waste tires in concrete. A mixture composed of ordinary concrete (Portland cement) and rubber from recycled tires has been presented in technical literature under the names of "Rubber Concrete" or "Rubber Modified Concrete". The rubber used in most cases was derived from post–consumption tires of motor vehicles and trucks subjected to mechanical tituration or to cryogenic processes. Given the applications and performances required by the final product, the rubber was used "as it is" or, in some occasions, the textile component was removed and the steel fibers unstrained. In other circumstances, the rubber surface was subjected to particular chemical pretreatments to reinforce adhesion of the rubber with the grout, obtaining a clear improvement of some final properties of the concrete. The latter solution has gained worldwide recognition in the engineering field, directing many researchers in recent years to carry out additional research on the use of waste rubber in concrete [Eldin and Senouci 1992, 1993a, b, Ali *et al.* 1993, Lee *et al.* 1998, Topcu, 1995, 1997, Fattuhi and Clark 1996, Toutanji 1996, Huynh and Raghavan 1996, Topcu and Avcular 1997, Li *et al.* 1996, Raghavan *et al.* 1998, Choubane *et al.*, 1999, Segre and Joekes 2000, Pierce and Blackwell 2003, Hernandez-Olivares and Barluenga, 2004, Siddique and Naik, 2004, Sukontasukkul and Chaikaew, 2006, Chou *et al.*, 2007, Topcu and Demir, 2007, Batayneh *et al.*, 2008, Ganjian et al., 2009].

Savas et al., [1996]; Benazzouk and Queneudec, [2002] and Paine et al., [2002] investigated the effect on freezing and thawing resistance of concrete mixes with rubber. Such research concluded that there is potential for using crumb rubber as a freeze–thaw resistance agent in concrete and that concrete with crumb rubber performed better under freeze–thaw conditions than plain concrete did. It has been reported by Hernandez-Olivares and Barluenga [2004] that the addition of crumb tire rubber to structural high-strength concrete slabs improved fire resistance, reducing the spalling damage by fire. On the other hand, several studies indicate that the presence of crumb rubber in concrete seems to lower mechanical properties (compressive and flexural strength when compared to conventional concrete. The decrease in strength is due to the lack of bonding between the rubber crumb and Portland cement. This decrease was found to be directly proportional to the quantity of rubber content. Also the size of the rubber crumbs appears to have an influence on strength. Coarse grading of rubber crumbs lowers compressive strength more than finer grading [Eldin and Senouci, 1993; Huynh and Raghavan, 1996; Fattuhi and Clarck, 1996; Eldin and Senouci, 1994 and Topcu, 1995, Sukontasukkul and Chaikaew, 2006; Batayneha et al., 2007]. Workability is found to decrease as the percentage of rubber increases due to the increasing viscosity of the mixture [Eldin and Senouci, 1993; Eldin and Senouci, 1999; Kathib and Bayomy, 1999]. The addition of tire rubber softens the elastic stress-strain response, yielding Young's moduli as low as 10,000 MPa [Goulias and Ali, 1997; Topcu and Avcular, 1997; Fedroff et al., 1996]. A wide overview of earlier studies is given by Siddique and Naik, [2004] and Ganjian et al., [2009].

Even though the mechanical properties of concrete seem to be downgraded by the presence of crumb rubber, there remain several other properties of concrete that benefit. One of the most significant benefits of tire rubber modified concrete is the reduction of mass density. Mass density can be reduced to as low as 1750 kg/m^3 [Eldin and Senouci 1993a; Khatib and Bayomy, 1999; Fedroff et al., 1996; Li et al. 1998]. Moreover, concrete mixed with crumb rubber up to about 30% of the cement weight is found to improve non-structure crack resistance, shock wave absorption and resistance to acid, offering lower heat conductivity and noise level reduction. In addition, crumb rubber concrete proved to be lighter in weight with its density reduced compared to conventional concrete [Topcu, 1995 and Rostami et al., 2000]. Some authors have also discussed the time-dependent properties of rubcrete, which may be critical in some cases. A study of Van Mier et al., [1997] for example, has revealed that the significant difference in Poisson's ratio of rubber particles and the cement-matrix encourages premature cracking. However, Turatsinze et al., [2006] indicated that the higher the content of rubber shreds, the smaller the crack length and width due to shrinkage, and the onset time of cracking was more delayed. It was further indicated by Hernandez-Olivares, et al., [2002] that the variations of the elastic modules experimentally obtained either under static or dynamic load increase with age. Moreover, Hernandez-Olivares et al., [2000], referred to the results of an experimental traffic road built in a residential area in Gudino (Spain), made of concrete filled with small volumetric fractions of crumbed tyre rubber. After 3 years of heavy use (cars and trucks), it still showed a very good performance. Thus, despite some well-known drawbacks, the results of many authors demonstrated that rubberised concrete exhibited some interesting properties, such as their straining capacity and toughness that encourages its use as a construction material. Although many authors do not recommend to use the modified concrete in structural elements where high strength are required, rubcrete can be used in many other construction elements [Batayneh et al., 2008]. Further research is needed in order to find a specific mix able to limit the strength-loss (for example by reducing the replaced rubber to a specified amount or by adding fly ash and yield a mix strength enough for novel applications where structure vibration control is required.

In this study, a number of laboratory tests were carried out on modified concrete specimens using rubber particles obtained from waste tires. Different percentages of rubber particles were used as a substitute to natural aggregates in the concrete mix.
The objectives of this paper are:

- to enhance the understanding of rubber concrete material properties through laboratory testing and field evaluation;
- to develop test information that can serve in drafting a practical rubber concrete mix specification for *non-structural* / *low-loading* usage;
- to evaluate the possible advantages of using rubber in concrete specification for *structural* usage and indicate a possible mix.

Through a series of the above-mentioned tests, these possible advantages were evaluated and the findings are discussed in the following sections.

EXPERIMENTAL PROCEDURE

Rubber properties. First, it is important to establish that tires can be divided into two categories, distinguishing: (1) car and (2) truck tires. Car tires are different from truck tires with regards constituent materials, especially natural and synthetic rubber contents. Considering the high volume of production of car tires as compared to truck tires, the former usually draws more interest [Ganjian et al., 2009]. The specification of the rubber source was very important and should always be specified in literature because it has an influence on

shape and texture and consequently on the characteristics of the concrete modified by the addition of the rubber. It was also important to underline that motor vehicle tires and truck tires differ not only in shape, weight and size, but above all in the proportion of the components of the base mixture. In fact, the quantity of rubber/elastomers was found to be greater in motor vehicles (48%) rather than in trucks (43%). The percentage of the textile component present was 5% in motor vehicle tires and null in truck tires, while the percentage of steel fibres was greater in truck tires (27%) rather than in motor vehicle tires (15%).
In this work, both types of waste rubber have been tested in order to compare their performance as aggregates in concrete. Three broad categories of discarded tire rubber have been considered (Figure 1):

1. C*hipped* rubber. The rubber has a dimension of about 25-30 mm. It was used to replace the coarse aggregates in concrete.
2. *Crumb* rubber. These particles are highly irregular, in the range of 3–10 mm. The rubber was used to replace sand.
3. *Ash* rubber. The rubber consists of particles smaller than 1 mm. It was not prepared from crumb rubber by grinding, but was the powder formed unintentionally during the trituration process, fallen from the machinery of the plant handling the waste rubber. It could be used as a filler in concrete due to its size.

Figure 1. Types of rubber used in the laboratory tests.

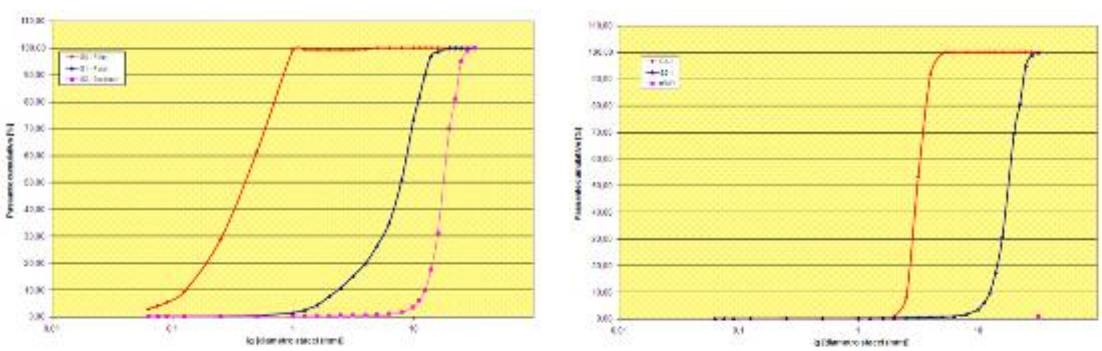
Details and assigned designations of each type of rubber are given in Table 1 and Figure 1. All of the rubber particles have been used in concrete mixes without chemical pre-treatment.
As can be noted in Table 1, the supply of chipped aggregates (G2) from truck tires is identical to that from car tires, while the crumb fraction (G1) was significantly smaller than that of car tires and looks more regular with a lesser percentage of steel and tissue fibers. The aforesaid samples of rubber were subjected to centrifugation in order to eliminate the trapped air. The volumic mass of the grains was determined according to code EN 1097 and the average of the volume mass of two separate samples was calculated. Finally, the three specimens were sampled according to UNI EN 932 – 2 and the sieve analysis through sifting (test portion washing, followed by dry sifting) was conducted with the purpose of determining sieve distribution in accordance to UNI EN 933.

The used rubber particles were obtained from a process of mechanical trituration of motor vehicle tires and partly or totally substituted “as they were” in different quantities and sizes natural inerts in the cement paste.

Figure 2 shows the gradation. It indicates a good sieve assortment, and a proper presence of the fine, medium and coarse fractions, obtaining a reduced content of interstitial voids.

Table 1. Properties of rubber particles

	Property	Laboratory designation			Reference code
		G0 (ash)	G1(crumb)	G2 (chips)	
Rubber from truck tires	Finess modulus	2,02	6,20	7,65	**UNI EN 933-1**
	Maximum size [mm]	1,00	14,00	25,00	**UNI EN 12620**
	Gradation class	[0-1]	[2,5 - 4]	[12,5 - 25]	**UNI EN 12620**
	Average bulk volume mass [kg/m^3]	1,09±0,024	1,12±0,021	1,12±0,092	**UNI EN 1097-6**
Rubber from car tires			**G1-1**	**G2-1**	
	Finess modulus		5,06	7,65	**UNI EN 933-1**
	Maximum size [mm]		4,00	25,00	**UNI EN 12620**
	Gradation class		[2,5 - 4]	[12,5 - 25]	**UNI EN 12620**
	Average bulk volume mass [kg/m^3]		1,12±0,021	1,12±0,092	**UNI EN 1097-6**



(a) **(b)**

Figure 2. Gradation of rubber from truck tires (a) and from car tires (b).

Mix proportions. Materials used in this study consisted of cement Portland type I and II, coarse and fine natural aggregates, sand and water. Specifically, two different types of cement were used:

- CEM 42,5R II-A/LL (composite Portland cement with limestone);
- CEM 52,5R I (Portland cement)

In the series of prepared mixes, three kinds of superplasticizer admixtures were added. For convenience, they are identified with the following designations: admixtures α, admixtures β and admixtures γ. α and γ are liquid superplasticizer admixtures with polymer of poliacrylic acid without sulphate and formaldehyde. The admixture γ differs from the first because it contains a viscous component capable of giving a more compact cement paste. The superplasticizer admixture β is specially formulated to lengthen the time of workability of the concrete up to a temperature of 50°C.

Mix with rubber from truck tires-Test series 1. Several tests were carried out at the CTG Laboratory (Italcementi Group) of Mesagne, Brindisi (Italy) and consisted of: (1) workability, (2) mass density and (3) compression tests. After the realization of several trial mixtures varying the cement type and dosage, the type of admixture, and the quantities of substitute rubber particles, two series of rubber-concrete mixes were obtained. The first series was composed of 8 mixes (0-PR; 1-PR; 2-PR; 3-PR; 4-PR; 6-PR; 7-PR; 8-PR) with a partial substitution involving rubber particles from truck tires. Table 2 shows the quantities and the respective sizes of the rubber samples used for the mixtures.

Table 2. Composition of the mixes with rubber from truck tires

Property	Specimen series							
	00-PR	**01-PR**	**02-PR**	**03-PR**	**04-PR**	**06-PR**	**07-PR**	**08-PR**
Cement type	CEM 42.5R II-A/LL	CEM 42.5R II-A/LL	CEM 42.5R II-A/LL	CEM 42.5R II-A/LL	CEM 42.5R II-A/LL	CEM 42.5R II-A/LL	CEM 52.5R I	CEM 42.5R II-A/LL
Cement quantity [kg/m^3]	400	450	450	400	400	450	450	400
c/w ratio	0,5	0,45	0,45	0,5	0,5	0,45	0,45	0,5
Sand [kg/m^3]	840,1	896,5	896,5	500,8	840,1	896,5	896,5	500,8
Fine rubble [kg/m^3]	258,9	251,2	251,2	-	258,9	251,2	251,2	-
Coarse rubble [kg/m^3]	-	-	-	405,3	-	-	-	405,3
G0 [kg/m^3]	**-**	**-**	**-**	**128,6**	**-**	**-**	**-**	**128,6**
G1 [kg/m^3]	**-**	**-**	**-**	**200,1**	**-**	**-**	**-**	**200,1**
G2 [kg/m^3]	**252,7**	**209,3**	**209,3**	**-**	**252,7**	**209,3**	**209,3**	**-**
Admixture	1,14%α	0,91%α	1,21%α	1,52%α	1,14% β	0,91%γ	1,21% γ	1,52% γ

The first four mixes are characterized by the same type of cement and admixture. In order to improve the compressive strength and reduce the air content, some adjustments were made to the afterwards mix. In detail, mix 04-PR was substantially based on mix 01-PR but contains a superplasticizer. In mix 06-PR, the quantity of cement was increased while in mix 07-PR the type of cement was also varied. Mix 08-PR was based on mix-00 but a different admixture with a viscous component was added to reduce the percentage of air absorption.

Results of test series 1. For each mixture, four cubic samples each 15 x 15 cm were prepared. The workability on the fresh concrete was measured with the Abrams' slump test, the air content expressed as volume ratio was tested through a pressure-type air meter and the volumic mass was estimated. On the hardened concrete, the compressive strength, tested on days 7 and 28, and the corresponding volumic mass were evaluated. In Table 3, the numerical results of the developed tests are summarized. The mix appeared to have a very good distribution of the rubber aggregates in the cement paste and did not show any signs of segregation (Figure 3.a). As can be noted from data collected in Table 3, all the aforesaid mixes belong to consistency class S3 (slump 100-150 mm) and S4 (slump 160-210 mm) –

see Figure 3.b. As expected, The compressive strength was found to decrease with an increase of the crumb rubber content.

Table 3. Properties of the test series 1

Property	00-PR	01-PR	02-PR	03-PR	04-PR	06-PR	07-PR	08-PR
Theoretic volume mass [kg/m^3]	1824	1951	1790,9	1912,9	1951,5	2011,2	2011,2	1836,3
Slump 0' [cm]	22	18	20	18	21	21,5	20	7
Slump 30' [cm]	-	13,5	21	18	21,5	22	20	7
Slump 60' [cm]	21	8	20	17,5	14	20	18	12
Fresh volume mass [kg/m^3]	1398,5	1911,4	1646,1	1599,4	1885,6	1975,5	1995	1701,9
Air content [%]	25	5,5	11	20	7,8	5,6	4,5	10
Volume mass at 7days [kg/m^3]	1431,9	1896,5	1536,2	1539,7	1880,1	1932,9	1992,9	1689,1
Compressive strength at 7 days [MPa]	3,04	10,01	3,95	4,27	11,64	16,14	20,79	5,86
Volume mass at 28days [kg/m^3]	1441,2	1887,7	1540,3	1550,6	1876,8	1961,8	2004,6	1690,7
Compressive strength at 28 days [MPa]	3,19	10,61	4,77	4,48	11,71	17,21	20,18	6,32

The obtainment of lightweight concrete by adding rubber crumbs was partly due to the lack of aggregates replaced by the rubber. Another cause could be the large voids created by the rubber particles inside the cement paste, leading to higher porosity.
According to the acquired results. the prepared mixes were classified in two groups:

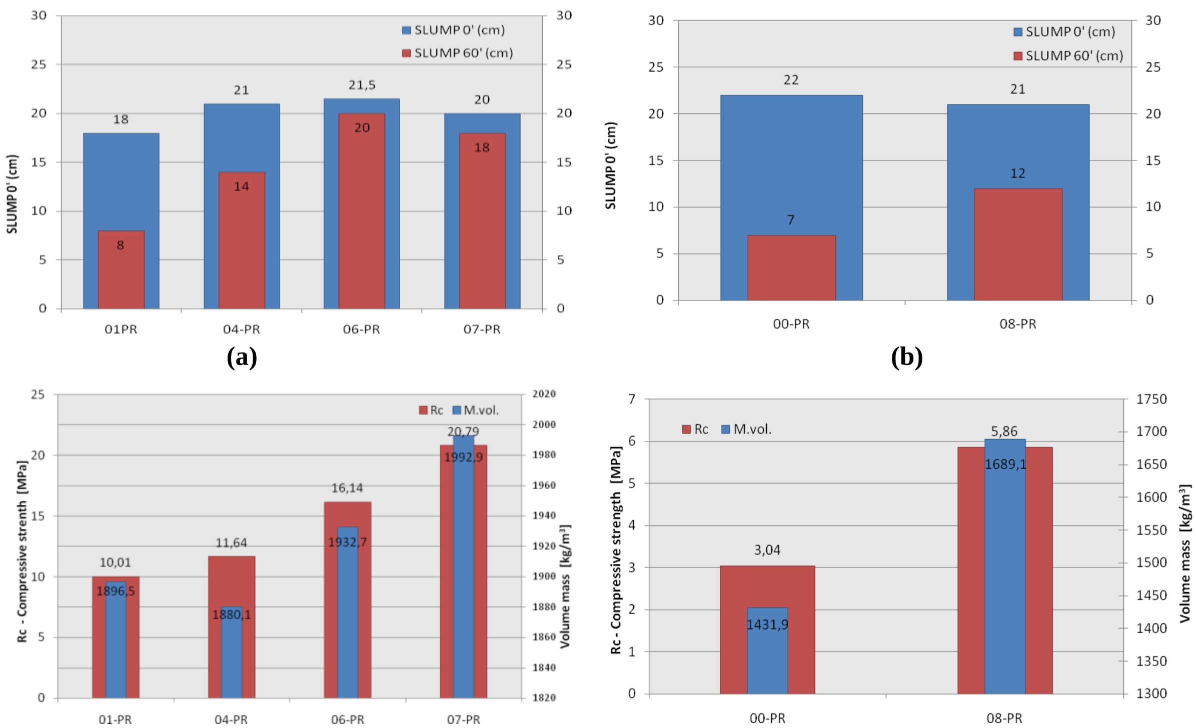
- Mixtures 01-PR, 04-PR, 06-PR and 07-PR were characterized by larger values of compressive strength, so they could be potentially used as rubber–concrete mixes for *structural applications*;
- Mixtures 00-PR and 08-PR were characterized by very small values of compressive strength but lower volume mass, so they could be potentially used as rubber–concrete mixes for *non-structural applications*.

In the figure 4 the main results on the different mixtures are compared.

Mix with rubber from car tires-Test series 2. Table 4 shows the composition of the second series of mixes, including rubber from car tires. Two mixes were tested by totally replacing natural aggregates with rubber (mix 011-PR and 012-PR) in order to obtain a lighter result for non-structural uses. Mix 012-PR differs from 011-PR only because of the type of admixture which lacks the viscous component in order to limit the water required. Mix 010-PR was based on the best mixes of the first series (06 and 07-PR) but with rubber from car tires.

(a) (b)

Figure 3. Examples of specimens with chipped rubber aggregates (figure a. at left) and crumbed rubber (figure a. at right) and workability of the mix (b).



(c) (d)

Figure 4. Workability for structural (a) and non-structural (b) mixes and compressive strength results for structural (c) and non-structural (d) mixes.

Table 4. Composition of the mixes with rubber from car tires

Property	**010-PR**	**011-PR**	**012-PR**
Cement type	CEM 52.5R I	CEM 42.5R II-A/LL	CEM 42.5R II-A/LL
Cement quantity [kg/m^3]	450	400	400
c/w ratio	0,45	0,5	0, 5
Sand	876,5	-	-

[kg/m^3]			
Fine rubble [kg/m^3]	245,5	-	-
Coarse rubble [kg/m^3]	-	-	-
G0 [kg/m^3]	**-**	**323,3**	**323,3**
G1-1 [kg/m^3]	**204,6**	**115,0**	**179,7**
G2-1 [kg/m^3]	**-**	**280,2**	**215,6**
Admixture	1,75% γ	1,37% γ	0.5% α

Results of test series 2. Results are gathered in Table 5. Mix 010-PR confirms very good workability (it belongs to an S5 class) and an appreciable compressive strength for structural applications, but contains a very high quantity of air. Mixes 011 and 012-PR, with 100% of rubber aggregates, show a desirable value of the volume mass but too little strength and an excessive water request (expecially mix 011-PR). In fact, due to the low specific gravity and high specific surface area of the rubber particles, the water requirement was significantly higher than that of concrete without rubber.

Table 5. Properties of the mix series 2

Property	010-PR	011-PR	012-PR
Theoretic volume mass [kg/m^3]	1981,6	1319,9	1319
Slump 0' [cm]	16	20	21
Slump 30' [cm]	21	-	-
Slump 60' [cm]	>S5 530mm S.F	21	8
Slump 90' [cm]	>S5 550mm S.F	-	-
Fresh volume mass [kg/m^3]	1952 a 0' e 1626 a 90'	1204	963
Air content [%]	6,3% a 0' e 21% a 90'	-	27
Volume mass at 7days [kg/m^3]	1715,3	1199,8	992,86
Compressive strength at 7 days [MPa]	11,38	0,74	0,67
Volume mass at 28days [kg/m^3]	1685,83	1209,7	963,3
Compressive strength at 28 days [MPa]	13,19	0,86	0,69
Additional water [kg/m^3]	-	251,1	152,2

CONCLUSIONS

The results presented in this paper show that the incorporation in concrete of rubber aggregates, obtained from waste tires, is a suitable solution to decrease weight in some engineering manufactures. Despite some drawbacks, such as the large decrease in compressive strengths, and the increase of water request and air content, the tests demonstrate that rubcrete mix possesses interesting properties that can be useful in structural and non-structural applications. The performance of concrete is significantly affected by the type and content of the rubber particle as well as by cement type and admixture properties. It may be concluded that:

- mix 07-PR with particles from truck tires and mix 010-PR with rubber from car tires satisfied the required qualifications of having a low specific gravity (<2100 Kg/m^3) and acceptable compressive strength for possible *structural applications*.
- mix 08-PR with particles from truck tires and 012-PR with rubber from car tires showed very low density (even <1000 kg/m^3), offering concrete useful for *non-structural applications*.

Further extensive research is needed to investigate the durability, the toughness and impact resistance of the mix and to optimize the mix here selected with the aim of reducing the levels of entrapped air and water absorption. On the basis of the present results, some mix designs were proposed in manufacturing concrete containing rubber up to about 100%. The resulting mixes were lighter, seemed to be more flexible and with a better energy absorption quality. Nevertheless, these latter mechanical properties have not been investigated in this research but will be object of future studies.

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