

## CONCRETE WITH CRUMB RUBBER FROM USED TYRES

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### Abstract

This study aims to determine the influence of the substitution of a variable volume of aggregates on a concrete by an equivalent quantity of crumb rubber (CR) obtained from used tyres. The physical and mechanical properties of different concretes, which were developed through laboratory tests, have been studied for this goal.

The experimental method employed is based on the production of a reference concrete and six concretes where part of the conventional aggregate has been replaced by particles of CR, keeping the proportion water-cement and cement content per cubic meter of concrete constant. Intending to assess the influence of the volume of CR incorporated into a conventional concrete, a first group of specimens is created, replacing 5%, 10% and 15% of the volume of sand in the original mix by grains of rubber 1-4 mm. In order to study the influence of the size of the incorporated grains of CR, a second group of specimens is produced substituting the content of the gravel for grains of rubber 10-16 mm, which leads us to three other types of concrete.

The addition of CR increases the rate of entrapped air due to the bad adherence between the cement paste and the CR grains. The consequence is a higher absorption and porosity. The compressive strength and the elasticity modulus decrease with the addition of rubber, but the tensile strength remains at the same level. The final conclusion of the study is that the use of concrete with CR is possible in several applications taking into account the limitations and advantages deduced from this experimental project.

### Key words

Concrete with CR; crumb rubber; partial replacement of aggregates; rubberised concrete; used tyres.

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## **1 INTRODUCTION**

Tyre consumption in developed countries is high and increases as the population rises. After their working life is over, used tyres become a solid waste that is difficult to get rid of. The European Union generated around 3.5 million tonnes of used tyres in 2012, according to data published by ETRMA [1], and approximately 5% of this waste was deposited in landfills or unknown places. The EU Directive on waste disposal [2] states that from 2006 no used tyres will be accepted in any landfill whether they are whole or shredded, with the exclusion of bicycle tyres and tyres whose diameter is more than 140 cm. A tyre's material or energy potential after its working life is over needs to be further addressed before its life cycle can be considered as a sustainable development model.

The need to find new uses for this bulky waste has led to the idea of using the particles obtained from mechanical shredding in concrete, replacing part of the conventional aggregates.

## **2 A BRIEF LITERATURE REVIEW**

The feasibility of adding rubber from crumb rubber (CR) to Portland cement concrete has been researched for slightly over two decades. Several authors [3-7] confirmed by means of laboratory tests that concrete mixtures with rubber lead to a decrease in compressive strength. However, they have a greater potential to deform plastically before rupture. To obtain concrete with acceptable strengths, they recommend that the rubber fraction added to the mixture must not be more than 20% of the total volume of aggregates.

The objective of this experimental study is to determine the impact of adding various percentages of rubber particles (5, 10 and 15% of the volume of conventional aggregates) on concrete's physical and mechanical properties. Consequently, various concretes were prepared using two CR particle sizes: fine 1-4 mm (CR-F) and coarse 10-16 mm (CR-C).

## **3 EXPERIMENTAL STUDIES**

### **3.1 Characterisation of the Materials**

The composition of a tyre varies depending on whether it is used for cars or lorries (Tab. 1), although rubber is the main component in both cases, virtually 50% of the tyre's total weight [8]. The rubber used in the manufacture of tyres for cars is usually natural rubber (NR), whilst for lorries it is synthetic styrene butadiene rubber (SBR). At the moment, the mechanical shredding of CR results in a product that is a mixture of car and lorry tyre particles, whose commercial brand and composition vary. There are some characteristics that stand out, depending on the natural or synthetic origin of the rubber. NR has more breaking strength, abrasion resistance, tensile strength and bond, whilst SBR has more compressive strength, heat resistance, hardness and permeability. The composition of the tyres can vary depending on the manufacturer, and this also alters their properties. As rubber behaves very differently depending on its type and manufacturer, it needs to be separated so that better use can be made of the recycled product. Consequently, it would be interesting to assess the effect of the type of rubber on concrete properties, as the latter may not necessarily be improved on the basis of the rubber used.

*Tab. 1: Tyre composition*

Component	Automobile	Trucks
Rubber/elastomers	45%	42%
Carbon black and silica	23%	24%
Metal	16%	25%
Textile	6%	-
Zinc oxide	1%	2%
Sulphur	1%	1%
Additives	8%	6%

The rubber used in this experimental study is SBR and it was obtained from the company Alfredo Mesalles, S.A., whose activity is CR recovery. The size of the rubber granulate added to the concretes varies depending on the aggregate it is replacing, which is 1-4 mm for sand and 10-16 mm for gravel. The sand is crushed limestone, with a dry density of 2.492 g/cm<sup>3</sup> and an absorption of 2.7%. The fine gravel is crushed limestone, with a dry density of 2.547 g/cm<sup>3</sup> and an absorption of 1.88%. The coarse gravel is crushed limestone, with a dry density of 2.610 g/cm<sup>3</sup> and an absorption of 1.42%. The cement chosen is CEM II Portland cement with a normal initial strength of 42.5 N/mm<sup>2</sup>. A chloride-free superplasticizer was added, SIKAMENT 500 HE, to improve the workability of the concrete.

### 3.2 Design of the Mixtures

Six concrete mixtures with the addition of rubber were designed for the experimental method based on a standard dosage for H25 concrete with normal hardening and a water/cement ratio of 0.65, which was kept constant in all the dosages (Tab. 2).

*Tab. 2: Mixture dosages*

Mixtures	Cement [kg/m <sup>3</sup> ]	Conventional Aggregates [kg/m <sup>3</sup> ]			Rubber Particles [Kg/m <sup>3</sup> ]		Water [Kg/m <sup>3</sup> ]	Additive [g/m <sup>3</sup> ]
		Sand 1-4 [mm]	Fine gravel 4-10 [mm]	Coarse gravel 10-16 [mm]	Fine 1-4 [mm]	Coarse 10-16 [mm]		
0%-CR	275	837	230	755	-	-	133	1567
5%-CR-F	275	795	230	755	16	-	133	1567
10%-CR-F	275	754	230	755	32	-	133	1567
15%-CR-F	275	712	230	755	47	-	133	1567
5%-CR-C	275	837	230	718	-	16	133	1567
10%-CR-C	275	837	230	680	-	32	133	1567
15%-CR-C	275	837	230	642	-	47	133	1567

A series of laboratory tests were conducted to determine the properties of the different concretes when fresh and hardened to obtain useful data that can help us to assess the impact of replacing conventional aggregates with CR aggregates.

A consistency test was conducted using Abrams' Cone to determine fresh concrete's resistance to deformations. Compressive strength, indirect tensile strength and elastic modulus were assessed by making 10x20 cm test cylinders. Central sections of this type of cylinder, approximately 5 cm thick, were used to obtain data on capillary absorption, on absorption, density and porosity percentages, and on the microstructure of the various mixtures.

## 4 EXPERIMENTAL RESULTS

### 4.1 Slump Test

The slump test was performed following standard UNE EN 12350-2:2009 [9]. The results show more slump in rubberised concretes. Variations determined by the rubber granule size were also observed, since concretes with CR-F have a more fluid condition than concretes with CR-C (Tab. 3).

*Tab. 3: Results of the slump test*

0% CR	CR-F			CR-C		
	5%	10%	15%	5%	10%	15%
8 cm	8 cm	12 cm	11 cm	9 cm	10 cm	9 cm

### 4.2 Capillary Absorption

The concrete's capillary absorption speed of water was measured by placing three samples of each concrete in contact with water at their base for 48 hours, and periodic readings were taken of their weight. The data obtained reveal that capillary absorption increases in rubberised concretes, and this is more pronounced the larger the diameter of the rubber particles is.

### 4.3 Density, Absorption and Porosity

To determine the density, absorption percentage and percentage of voids in the hardened concrete, three samples of each mixture were immersed for 48 hours and dried in an oven at 100°C for 24 hours and the data of the various masses of the specimens were obtained. The test was performed using standard UNE EN 12390-7:2009 [10] and the laboratory's internal methodology. The values obtained show an increase in the absorption percentage and porosity of rubberised concretes, and it is higher in those concretes with coarse rubber particles. Rubberised concretes have a lower density than that of conventional concrete.

### 4.4 Compressive Strength

The compressive strength of the hardened concrete was determined by subjecting three specimens from every mixture to compressive stress until the maximum bearing load was reached. The test was performed following standard UNE EN 12390-3:2009 [11]. The data show a decrease in the compressive strength in concretes with added rubber. However, the fall in strength is not proportional, since the strengths of concretes with 10% and 15% of CR are very similar. As the CR granule size increases, the concrete strength decreases.

#### **4.5 Indirect Tensile Strength**

The indirect tensile strength test or “Brazilian test” was used on two specimens of each concrete to obtain the pure tensile strength value, and then the conversion system described in EHE-08 [12] was used. The test was performed following standard UNE EN 12390-6:2010 [13]. In view of the results obtained, it can be considered that all the concretes have the same strength level, and, therefore, the replacement of the conventional aggregate by CR does not alter tensile strength. On further analysis of the data, it can be seen that concretes with CR-F have slightly higher strengths than concretes with CR-C.

The rubberised concrete specimens subjected to the indirect tensile test fractured, but they did not separate, unlike the conventional concrete specimens, as rubber has ductile properties that are superior to those of conventional aggregates.

#### **4.6 Elastic Modulus**

To determine the elastic modulus, or Young’s modulus (E), stress equivalent to  $\frac{1}{3}$  of the concrete’s compressive strength was applied to three specimens of each concrete, and the deformation of the various concretes was measured in each case. The test was performed following standard UNE EN 83316:1996 [14]. The elastic modulus of the rubberised concretes tends to decrease as the rubber content increases. Therefore, concretes with CR deform very easily when there is compressive stress. The results obtained do not show any variation in the elastic modulus connected with the size of the replaced CR particle.

### **5 DISCUSSION**

Rubberised concretes undergo a slump when fresh that is higher than that of conventional concrete.

Adding CR promotes air in concrete when fresh as there is a low bond between the CR granules and the cement paste. Smaller-sized rubber has a better bond with the paste, since it is far more spherical, despite not being as good as that of conventional aggregate. Concretes with CR offer more absorption and porosity, which increase with the size of the rubber particles. This rise in voids in the mixture, together with the low density of the rubber compared with that of conventional aggregate, are factors that have an influence on lowering the concrete’s density.

The concrete’s compressive strength decreases when rubber is added. This reduction depends on the size of the rubber granule, in other words, as the latter increases, the concrete’s strength decreases. The concrete’s tensile strength is not altered by adding CR, but if the average values are analysed, tensile strength can be considered to drop much more discreetly than compressive strength and it even increases in concretes with 5% of CR. The elastic modulus decreases as the CR content increases, since conventional aggregate is being replaced by a much more elastic material. Concrete with rubber deforms easily in the presence of compressive stress that is lower than the value of the concrete’s compressive strength.

### **6 CONCLUSIONS**

The following main conclusions on rubberised concrete are deduced from the results obtained in this experimental study:

- Workability is good, making fast onsite placement possible.
- Compressive strength is not high, achieving values between 25 and 32 MPa.
- Tensile strength is not altered when rubber is added.
- The capacity to deform when there are compressive stresses below the maximum strength is high.

The addition of rubber particles obtained from used tyres in conventional concrete is feasible if low compressive strengths are expected.

After analysing the bonds of the various components, a lack of contact was noticed between the CR granules and the cement paste. Further research needs to be undertaken to improve the adherence between rubber and paste.

The durability of rubberised concretes needs to be studied to determine their capacity to resist the action of the atmosphere, chemical, physical and biological attacks, or any process that tends to deteriorate them.

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