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# TYRE RUBBER WASTES BASED CONCRETE: A REVIEW.

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## ABSTRACT

The volume of tyre rubber wastes is increasing at a fast rate. An estimated 1000 million tyres reach the end of their useful lives every year and 5000 millions more are expected to be discarded in a regular basis by the year 2030. Up to now a small part is recycled and millions of tyres are just stockpiled, landfilled or buried. This paper reviews research published on the performance of concrete containing tyre rubber wastes. It discusses the effect of waste treatments, the size of waste particles and the waste replacement volume on the fresh and hardened properties of concrete.

**Keywords:** Tyre rubber wastes; concrete; properties; durability

## INTRODUCTION

Tyre rubber wastes represents a major environmental problem of increasing relevance. An estimated 1000 million tyres reach the end of their useful lives every year. At present enormous quantities of tyres are already stockpiled (whole tyre) or landfilled (shredded tyre), 3000 millions inside EU and 1000 millions in the US [1]. By the year 2030 the number of tyres from motor vehicles is expect to reach 1200 million representing almost 5000 millions tyres to be discarded in a regular basis. Tyre landfilling is responsible for a serious ecological threat. Mainly waste tyres disposal areas contribute to the reduction of biodiversity also the tyres hold toxic and soluble components [2]. Secondly although waste tyres are difficult to ignite this risk is always present. Once tyres start to burn down due to accidental causes high temperature take place and toxic fumes are generated besides the high temperature causes tyres to melt, thus producing an oil that will contaminate soil and water. In Wales a tyre dump with 10 million tyres has been burning continuously for nine years [3]. The implementation of the Lanfill Directive 1999/31/EC and the End of Life Vehicle Directive 2000/53/EC banned the landfill disposal of waste tyres creating the driving force behind the recycling of these wastes. Still millions of tyres are just being buried all over the world. Tyre rubber wastes are already used for paving purposes, however, it can only recycle a part of these wastes [4]. Another alternative are artificial reef formation but some investigation have already questioned the validity of this option [5]. Tyre waste can also be used in cement kilns for energetic purposes and to produce carbon black by tyre pyrolisis [6], a thermal decomposition of these wastes in the absence of oxygen in order to produce by-products that have low economic viability. Some research has already been conducted on the used of waste tyre as aggregate replacement in concrete showing that a concrete with enhanced toughness and sound insulation properties can be achieved. Rubber aggregates are obtained from waste tyres using two different technologies: mechanical grinding at ambient temperature or cryogenic grinding at a temperature below the glass transition temperature. The first method generates chipped rubber to replace coarse aggregates. As for the second method it usually produce crumb rubber to replace fine aggregates. In this work the most relevant knowledge about the properties and the durability of concrete containing tyre rubber wastes will be reviewed. Furthermore it discusses the effect of waste treatments, the size of waste particles and the waste replacement volume on the fresh and hardened properties of concrete. Investigations carried out so far reveal that tyre waste concrete is specially recommended for concrete structures located in areas of severe earthquake risk and also for applications submitted to severe dynamic actions like railway sleepers. This material can also be used for non load-bearing purposes such as noise reduction barriers. Investigations about rubber waste concrete show that concrete performance is very dependent on the waste aggregates. Further investigations are needed to clarify for instance which are the characteristics that maximize concrete performance.

## FRESH CONCRETE PROPERTIES

### Workability

Albano et al. [9] replace fine aggregates by 5% and 10% of scrap rubber waste (particle sizes of 0.29mm and 0.59mm) reporting a decreased of 88% in concrete slump. Bignozzi & Sandrolini [10] used scrap-tyre (0.5 to 2mm) and crumb-tyre (0.05 to 0.7mm) to replace 22.2% and 33.3% of fine aggregates in self-compacting concretes referring that the introduction of the rubber particles does not influence the workability in a significant way if the superplasticizer also increases. Skripkiunas et al. [11] used crumbed rubber to replace 23 kg of fine aggregates in concretes with 0.6% of a policarboxile superplasticizer by cement mass obtaining the same workability of the reference concrete. Other authors [12] used crumb rubber tyres (0.075 to 4.75mm) in the concrete to replace sand in various percentages (20%, 40%, 60% and 100%). These authors stated that increasing rubber waste content decreases the concrete slump (Table 1).

Table 1 – Slump performance according to crumb rubber content [12]

| Rubber content (%) | Slump (mm) |
|---|---|
| 0 | 75 |
| 20 | 61 |
| 40 | 36 |
| 60 | 18 |
| 80 | 10 |
| 100 | 5 |

Freitas et al. [13] used scrap-tyre (0.15 to 4.8mm) in the replacement of sand reporting a slump decrease along with the increase of scrap-tyre content. However, these authors used 1% by cement mass of an unknown plasticizer in the mixtures with tire wastes, so the workability reduction is probably related to the low performance of the plasticizer. Topçu & Bilir [14] studied the influence of rubber waste with a maximum dimension of 4mm in self-compacting concretes noticing that rubber replacing sand increase concrete workability which is due to the presence of viscosity agents even to a volume of 180kg/m$^3$. Aiello & Leuzzi [15] used tyre shreds (Fig. 1) to replace fine and coarse aggregates (10mm to 25mm) with 1% by cement mass of a plasticizer observing increase workability with tire shreds content.

Fig.1 – Rubber particle during the mixture of concrete [25]

Guneyisi [16] used crumb rubber waste to replace sand in self-compacting concretes in different percentages (5, 15 and 25) and using also a polycarboxylic superplasticizer with different amounts. This author noticed that the mixture with 25% of rubber waste although containing 4% by cement mass of the superplasticizer did not achieved the target slump flow of 750mm ± 50mm. He also reported that adding fly ash helps to lower the amount of superplasticizer in the mixtures with high rubber waste content. Although the majority of investigations show that rubber aggregates lead to a decrease in concrete workability some authors reported the no workability loss and others even observed the opposite behaviour this means that workability is very dependent on the characteristics of the rubber aggregates. Future investigations should study what rubber wastes could be used to produce self-compacting concretes.

## HARDENED CONCRETE PROPERTIES

### Compressive strength

Guneyisi et al. [17] mentioned that the strength of concretes containing silica fume, crumb rubber and tyre chips decreases with rubber content. These authors suggest that it is possible to produce a 40MPa concrete replacing a volume of 15% of aggregates by rubber waste. Ghaly & Cahill [18] studied the use of different percentage of rubber in concrete (5%, 10%, and 15%) by volume also noticing that as rubber content increase leads to a reduction of compressive strength. Valadares [19] studied the performance of concretes with the same volume replacement of rubber wastes confirming the decrease of compressive strength. Ganjian et al. [20] also confirmed the decrease in compressive strength for increase rubber content. However, these authors obtained a slight increase in compressive strength when 5% of chipped rubber replaced the coarse aggregates probably due to a better grading of the mixture. This finding had already caught the attention of other authors [21,22]. Snelson et al. [23] used concretes with shredded tyre chips (15 to 20mm) for aggregate replacement in several percentages (2.5%, 5% and 10%) reporting a loss in compressive strength. The results show that the rubber mixtures also containing pulverised fuel ash as partial cement replacement presented major compressive strength loss. This means that the low adhesion between the cement paste and the rubber waste becomes even lower if admixtures with low pozzolanic activity are used. Aiello & Leuzzi [15] used tyre shreds to replace fine and coarse aggregates concluding that the size of the rubber particles have a major influence on the compressive strength. When coarse aggregates are replaced by the tyre particles the compressive strength loss is much more profound when compared to the compressive strength loss of concretes in which fine aggregates were replaced by rubber particles (Table 2).

Table 2 – Compressive strength of concrete with aggregates replaced by rubber particles [15]

| Mixture | Compressive strength (MPa) | Compressive strength decrease (%) |
|---|---|---|
| Reference concrete with rubber waste replacing coarse aggregates (W/B=0.52) | 45.8 | - |
| 25% rubber vol. | 23.9 | 47.8 |
| 50% rubber vol. | 20.9 | 54.4 |
| 75% rubber vol. | 17.4 | 61.9 |
| | | |
| Reference concrete with rubber waste replacing fine aggregates (W/B=0.60) | 27.1 | - |
| 15% rubber vol. | 24.0 | 11.6 |
| 30% rubber vol. | 20.4 | 24.7 |
| 50% rubber vol. | 19.5 | 28.3 |
| 75% rubber vol. | 17.1 | 37.1 |

These results contradict the ones presented by Valadares [19] and that may be related to the origin of the wastes used in each case (car, truck or motorcycle) being that different origin may possess different chemical compositions leading to different adhesion between the cement paste and the rubber waste. Vieira et al. [8] studied three types of rubber waste and three volume percentages (2.5%; 5% and 7.5%) reporting that the best mechanical performance was obtained using just 2.5%

of the tire rubber with 2.4mm. Several authors mentioned the use of pretreatments of rubber waste to increase the adhesion between the cement paste such as the use of a 10% NaOH saturated solution to wash the rubber surface during 20 minutes [24,25]. Raghavan et al. [26] confirms that the immersion of rubber in NaOH aqueous solution could improve the adhesion leading to a high strength performance of concrete rubber composites. The NaOH removes zinc stearate from the rubber surface, an additive responsible for the poor adhesion characteristics, enhancing the surface homogeneity [27].Segre et al. [28] mention several pretreatments to improve that the adhesion of rubber particles like acid etching, plasma and the use of coupling agents. Cairns et al. [5] used rubber aggregates coated with a thin layer of cement paste (Fig.2).

Fig.2 – 20 mm rubber aggregate particles: a) Plain; b) Coated with cement paste [5]

Oikonomou et al. [29] mentioned that the use of SBR latex enhances the adherence between the rubber waste and the cement paste. Chou et al. [30] suggest the pretreatment of crumb rubber with organic sulfur stating it can modify the rubber surface properties increasing the adhesion between the waste and the cement paste. Investigations about rubber waste concrete show a compressive strength loss with waste content increase. Further investigations are needed on this subject, especially to comprehend if different kinds of rubber behave in a similar manner to the same treatment.

**TOUGHNESS**

Concrete composites containing tyre rubber waste are known for their high toughness [31], having a high energy absorption capacity. The ASTMC1018-97 [32] defines several toughness indexes ($I_5$, $I_{10}$ and $I_{20}$) as the area under load-deflection curve of a flexural specimen for different times of deflection after crack initiation related to area under the same curve up to the crack initiation. Some authors [33] report a 63.2% increase in the damping ratio (self capacity to decrease the amplitude of free vibrations) for concrete containing 20% rubber particles. Other authors [34,35] confirmed the high damping potential of rubber waste concrete. They mentioned that concrete with ground rubber shows a 75.3% increase in the damping ratio and a 144% for crushed rubber concrete (Fig.6). Fioriti et al. [36] mentioned that concrete paving blocks containing 8% of tyre rubber waste (have a resistant impact of almost 300% when compared to the reference concrete. These means that tyre waste concrete maybe specially recommended for concrete structures located in areas of severe earthquake risk and also for the production of railway sleepers.

**MODULUS OF ELASTICITY**

Since the concrete with rubber waste has low compressive strength and a correlation exists between compressive strength and the modulus of elasticity it is expected they also possess lower modulus of elasticity. However, Skripkiunas et al. [21] compared concretes with similar compressive strength (a reference one and another with 3.3% of crumb rubber) obtaining different static modulus of elasticity, 29.6 GPa versus 33.2GPa for the reference concrete just 11% higher. The explanation for this behaviour is related to the low modulus of elasticity of rubber waste [37]. Other authors [38] report a decrease in the modulus of elasticity of 40% when the same percentage reduction takes place for compressive strength. Khaloo et al. [39] confirmed that the inclusion of tyre rubber particles leads to a high ductility concrete. Zheng et al. [34,35] mentioned that the crumb rubber (80%<2,62mm) has a lower influence in the modulus of elasticity than the crushed rubber (15-40mm). Other authors [40] studied the modulus of elasticity of concrete columns with two different sizes of crumb rubber (0.6 and 1mm) reporting an increase in the ductility performance up to 90%. Those authors mentioned that crumb rubber concrete columns can undergo twice the lateral deformation before failure compared to the reference concrete columns. Mohammed [41] confirmed that concrete slabs containing crumb rubber with a finesses modulus of 2.36 shows a higher ductility behaviour which fulfill the ductility requirements of Eurocode 4 [42].

**DURABILITY**

Since rubber waste concrete has lower compressive strength than reference concrete it is expected that is behaviour under fast mechanical degradation actions could also be lower. Topçu & Demir [43] mentioned that a high volume replacement of sand by rubber waste (1-4mm) has lower durability performance assessed by freeze-thaw exposure, seawater immersion and high temperature cycles. According to them the use of a 10% replacement is feasible for regions without harsh environmental conditions. Ganjian et al. [20] studied the durability of concrete containing scrap-tyre wastes assessed by water absorption and water permeability revealing that a percentage replacement of just 5% is associated with a more permeable concrete (36% increase) but not a more porous one. Increasing the rubber percentage replacement to 10% doubles the concrete water permeability which means this kind of concrete cannot be used for applications where water pressure is present like underwater columns. The durability of rubber waste concrete is a subject that needs further investigations. How different wastes influence durability parameters and most importantly how waste treatment can enhance the concrete durability are questions that must be addressed.

**CONCLUSIONS**

Tyre rubber wastes represent a serious environmental issue that needs to be addressed with urgency by the scientific community. Investigations carried out so far reveal that tyre waste concrete is specially recommended for concrete structures located in areas of severe earthquake risk and also for applications submitted to severe dynamic actions like railway sleepers. This material can also be used for non load-bearing purposes such as noise reduction barriers. Investigations about rubber waste concrete show that concrete performance is very dependent on the waste aggregates. Further investigations are needed to clarify for instance which are the characteristics that maximize concrete performance. Nevertheless, future investigations should clarify which treatments can maximize concrete performance being responsible for the lowest environmental impact.

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