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Mechanical performance and medium-term degradation of rubberised concrete

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HIGHLIGHTS

- Effect of tyre-rubber partial substitution to natural aggregate in concrete is investigated.
- Mechanical retrogradation, cracking and volumetric expansion occur in rubbercrete cured in moist environment after 60 days.
- Chemical and microstructural analysis of degradated rubbercrete show no anomaly.
- The most plausible hypothesis for degradation is that rubber swells in alkaline environment.
- Imperflux-based surface treatments of rubber can prevent degradation in rubbercrete.

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ABSTRACT

This laboratory study deals with a comprehensive investigation of modified concrete specimens using rubber particles obtained from End of Life Tyres (ELT). Different types of mixes have been studied with different percentages of rubber particles used as a partial substitute for natural aggregates by using and comparing mixtures with various types of addition and surface treatment. Three types of rubber particles (ash rubber, crumb rubber and tyre chips) have been employed in the rubberised concrete mixtures replacing partially the natural aggregates. Test results shown that the rubberised concrete mix had some appealing characteristics such as a low mass density but worse compressive strength in line with previous studies. Among the most important findings, a decline in mechanical performance was observed in rubberised concrete specimens at an age of about 60 days. Moreover, cracking and delamination phenomena occurred on the test specimens cured under moist conditions which have never been described in the literature so far. The main innovation is in description of these results regarding time-dependent degradation of rubberised concrete and in a preliminary investigation about the causes of this phenomenon.

1. Introduction

In recent years, a number of research studies have focused on the use of different shapes and sizes of waste tyres in concrete. A mix concrete composed of ordinary Portland cement and rubber from recycled End of Life Tyres (ELT) has been presented in technical literature under the name of "Rubber Concrete" or "Rubber Modified Concrete". The rubber used in most cases derived from post-consumption tyres of motor vehicles subjected to shredding or to cryogenic processes. Given the applications and performance required by the final product, rubber was used "as it is" or, in some occasions, the textile component was removed and the steel fibres pulled out. In other circumstances, the rubber surface was subjected to particular chemical pretreatments in order to reinforce adhesion of the rubber with the grout, obtaining a clear improvement of some final concrete properties. This solution has gained worldwide recognition in the engineering field, leading many researchers in recent years to carry out additional research on the use of waste rubber in concrete [5,1,12,22,23,6,25,10,23,13,16,4,18,15,9,20,21,3,24,2,7]. A comprehensive overview of earlier studies is given by Siddique and Naik [20], Ganjian et al. [7], Xue and Shinozuka [28], Ossola and Wojcik [14].

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However, fewer are the studies dealing with the time-dependent properties of rubberised concrete, which may be critical in some cases. A study by Van Mier et al. [29] for example, has revealed that the significant difference between the Poisson's ratio of rubber particles and that of the cement matrix encourages premature cracking. However, Turatsinze et al. [26] indicated that the onset time of cracking was delayed. Also Hernandez-Olivares et al. [8] 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), the authors refer that it still perform very well.

The present investigation originates from an existing research work [19] and aims to widely explore the effects of rubber in concrete. It develops test information that could be helpful to draw up a practical rubber concrete mix specification for non-structural/low-load usage. Today further studies are actually needed to identify a special mix able to limit strength loss with the aim of obtaining a strong enough mix for novel applications where structure vibration control is required. During testing, however, the authors observed anomalous cracking and delamination phenomena on hardened concrete specimens at medium-term curing times which have never been reported or commented in the literature. To understand the causes for such an abnormal development of mechanical properties in rubberised concrete, additional special tests have been conducted and illustrated in this paper.

In brief, the experimental work is aimed at:

- enhancing the understanding of rubber concrete material properties, looking at both mechanical and physical & chemical aspects through laboratory testing and field evaluation;
- understanding the cracking and degradation phenomena observed at medium-term curing times through a series of specific tests and discussing the findings.

2. Materials and properties

Tyres can be divided into two main categories, i.e. (1) car and (2) truck tyres. Car tyres are different from truck ones in terms of their constituent materials, and specifically because of their natural and synthetic rubber contents. Considering the higher car tyre manufacturing volumes as compared to trucks, it's no surprise that the former usually draws more interest [7]. The specification of the rubber source is very important and should always be given in literature because it affects both shape and texture and consequently the characteristics of the concrete modified by the addition of the rubber. It is also important to underline that motor vehicle tyres and truck tyres differ not only in shape, weight and size, but above all in the basic mix proportions of the components. In fact, the quantity of rubber/elastomers was found to be greater in motor vehicles (48%) rather than in trucks tyres (43%). The percentage of the textile component present was 5% in motor vehicle tyres and null in truck tyres, while the percentage of steel fibres was greater in truck tyres (27%) rather than in motor vehicle tyres (15%).

In this work, car-type tyres have been tested; three broad categories of discarded tyre rubber have been considered (Fig. 1):

- *Chip rubber.* The rubber was about 25–30 mm in size. It was used to replace the coarse aggregates in the concrete mixes.
- *Crumb rubber.* These rubber particles were highly irregular, in the range of between 3 and 10 mm. This rubber type was used to replace sand in the concrete mixes.
- *Ash rubber.* This rubber consisted of particles smaller than 1 mm. It was not prepared from ground crumb rubber, but was the by-product powder formed during the shredding 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.

Details and codes assigned to each type of rubber are given in Table 1 and Fig. 1.

As can be noted in Fig. 1, the supply of chipped aggregates (G2-1) looks very heterogeneous, while the crumb fraction (G1-1) is more uniform with less amount of steel and tissue fibers. The aforesaid rubber samples were subjected to centrifugation to eliminate trapped air. The three specimens were sampled according to UNI EN 932-2 and the sieve analysis (test portion washed and then subjected to dry sifting) was conducted with the purpose of determining sieve distribution in accordance to UNI EN 933.

The rubber particles were obtained from a process of mechanical shredding of motor vehicle tyres and used "as it is" as a partial or total substitution of natural aggregates in the cement pastes. As later discussed, in some mixtures, the G2-1 aggregates were screened at 20 mm (chip 20) to remove too large chips.

Fig. 2 shows gradation of the rubber particles. The curves indicate a good sieve range and a proper presence of fine, medium and coarse fractions, which promotes fewer interstitial voids.

In the experimentation below, an investigation of the properties of leachate from the rubber used has been conducted. Prior art on leachate derived from crumb rubber showed no deleterious effect of rubber from ELT on the environment [12]. Observation of the data contained in leaching tests shows a pH of 7.91 and density of 0.98 kg/dm^3. Heavy metal concentrations are given in Table 2.

Concentrations of all other heavy metals are below the detection limits. Leaching tests to determine acceptability of non-hazardous waste landfill according to ENV 12457-2/04 have detected the concentrations given in Table 3. As can be seen, the presence of heavy metals such as zinc and the presence of sulfates and chlorides may potentially interfere with the hydration reaction of cement.

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

Table 1
Properties of rubber particles.

Property	Laboratory code			Reference standard
	G0-1	G1-1	G2-1	
Fineness modulus	2.02	5.06	7.65	UNI EN 933-1
Maximum size [mm]	1.00	4.00	25.00	UNI EN 12620
Gradation class	[0–1]	[2.5–4]	[12.5–25]	UNI EN 12620
Average bulk volume mass [kg/dm^3]	1.09 ± 0.024	1.12 ± 0.021	1.12 ± 0.092	UNI EN 1097-6
Water absorption [%]	0	0	0	UNI EN 1097-6