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Discovery

Use of tyre rubber in Self Consolidated Concrete

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ABSTRACT

Self-consolidated concrete is a special type of concrete which requires less workability and is easy to stabilize. Self-consolidated concrete using rubber is set up to consume the waste tyre rubber containing different types of untreated tyre rubber. Fine aggregates are replaced by weight with tyre rubber. The mechanical and micro structural behavior are investigated and discussed in this paper. The fresh and hardened properties of such materials are compared with those of a typical reference formulation of self-compacting concrete. A comparison of the obtained compressive strengths with literature data confirms that self-compacting technology helps binding rubber phases.

1. INTRODUCTION

The possibility of making concrete tough has been generally pursued by introducing rubber phases among the traditional components (cement, water and aggregates) and this idea has been largely investigated using, for this purpose, recycled grinded tyre rubbers. Different kinds of tyres have been employed as partial substitute of natural aggregates in concrete scrap tyres obtained by simple grinding without further purifications thus including steel and textile fibers in their composition, crumb rubber obtained by cryogenic process, milled tyre rubbers treated with sodium hydroxide solution to achieve a better adhesion with the cement paste, scrap truck tyre rubber (Li et al. 2004), tyres tread, etc. However, regardless the different nature, size and composition of used tyre rubbers, a meaningful decrease in concrete compressive strength with the increasing amount of rubber phase in the mixture was always detected. Although the so far obtained rubberized concrete generally shows a tougher behavior with a gradual failure of the samples than traditional concrete, it generally does not exhibit suitable compressive strength for structural applications. On the other hand, concrete has undergone several changes in its formulation and technology to become stronger and durable: with this purpose fly ashes, polymers, silica fume, super plasticizer, etc. have been added to the traditional mix and recently self-compacting characteristics have been achieved for tailored preparations. Self-compacting concrete (SCC) (Bignozzi et al. 2004), although developed with the aim to make easier compaction, is a new type of concrete that attains higher compressive strength and durability in comparison with ordinary Portland cement concrete (OPCC), thanks to the addition of fine filler and proper admixtures, i.e. super plasticizers and modifying viscosity agents. The combination of these components leads to a mixture that does not require vibrations on placing, with time and cost saving of building site procedures. However, in spite of the fine filler presence (usually with an average size about 10–30 μm) promoting the formation of very compact microstructure and allowing high values for compressive strength, the failure behavior in SCC is still brittle.

The possibility to design self-compacting rubberized concrete (SCRC) (Skarendahl et al. 2000) appears particularly attractive because this new material might join the characteristics of SCC (high flow ability, high mechanical strength, low porosity, etc.) with the tough behavior of the rubber phase, thus leading to a building material with more versatile performances. Previous studies have been carried out to verify the feasibility of SCRC: self-compacting rubberized mortars were prepared to evaluate the optimum amount of tyre rubber that could be introduced in the mix avoiding severe loss of compressive strength and still maintaining the self-compacting characteristics. The best results for workability and mechanical strength were obtained when sand fraction was replaced by tyre waste of similar grain size, instead of the substitution of fine filler fraction with equivalent grain size tyre rubber waste. Accordingly, in this work, three different concrete mixes were designed with the same water /cement (W/C) and water / powder (W/P, with P=cement +fine filler) ratios, but containing respectively 0, 20 and 30 vol.% of grinded tyre rubber as fine aggregate in substitution of sand: their self-compacting characteristics and final mechanical behavior are reported and discussed.

2. EXPERIMENTAL DETAILS

2.1. Concrete mix design

The following materials were used: ACC ordinary Portland cement as binder, alluvial coarse aggregates (4/16 mm) and sand (0/4 mm) roughly combined. The tyre rubber (TR) aggregates were obtained by mechanical grinding of tyre rubber waste: therefore they may still contain small amounts of steel and fabric residues. Two different grain size distributions were chosen: scrap (ST) and crumb (CT) tyres with size ranges 0.5 to 2 mm and 0.05 to 0.7 mm, respectively. They were sorted out to conform to sand grain size distribution (55% ST, 45% CT). Commercial products were used as admixtures: an acrylic based super plasticizer (SP, ''EUCOPLACANT 721'') and a modifying agent (VMA, Viscofluid "STRUCTURO 100").

SCC compositions are reported in Table 1. SCC-A mix is a formulation for self-compacting concrete, with water /cement and water /powder mass ratios of 0.53 and 0.34, respectively, adjusted in previous works. The same W/C and W/P mass ratios were used in SCC-B and SCC-C where respectively 20 and 30 v/v% of sand were replaced by tyre rubber wastes (Table 1). The concrete (Mazloom et al. 2004) mixes were prepared in a laboratory concrete mixer where coarse and fine aggregates, tyre rubber, filler and cement were fed in this order and mixed for 2 min; 75% of the water and the admixtures with the remaining water were then added. The admixtures were added, as reported in Table 1, to obtain self-compacting properties, which were determined for all the mixes according to test methods developed by other authors and Indian standards. The amount of super plasticizer increased with the amount of tyre rubber wastes in concrete. Total mixing time, starting from the introduction of concrete components, was usually about 12 min for each mix.

3. RESULTS AND DISCUSSION

3.1. Fresh concrete behavior

Fresh concrete tests were carried out: slump flow test was performed to evaluate flow ability of concrete also in the presence of obstacles (such as steel bar reinforcements). The cohesiveness and the absence of segregation of the mixtures were visually estimated. In Table 2, the average diameter of the spread concrete after slump flow is reported. Slump flow test results are greater than 650 mm for all the mixes as prescribed by Indian standard. Concrete viscosity was determined measuring the time (t500) required to reach a 500 mm spread diameter in the slump flow test: for all the formulations t500 was ≤5 s, according to the limit value of 12 s reported in Indian standard. The introduction of the investigated amount of tyre rubber particles in concrete does not influence in significant way the fresh concrete behavior.

3.2. Hardened concrete behavior

Concrete cubic samples (150×150×150 mm) were cast without any mechanical compaction and cured for 28 days at average of 20 °C. Water absorption (WA %) measurements were carried out on hardened concrete samples, at atmospheric pressure to evaluate the effects of tyre rubber wastes addition on concrete microstructure. The obtained values indicate a very slight increase in porosity with the rubber phase in the mixes, probably due to some deviations of rubber particles from sand grain size distribution and/or a slightly higher air amount trapped during mixing procedure of rubberized concrete. The decrease in strength and stiffness is strictly connected with the presence of the rubber phase: under compressive load, tyre rubber particles debond from cement paste causing voids that unavoidably make failure easier.

Table 1

Mix proportions of different SCC mixtures

Materials	SCC-A	SCC-B	SCC-C
Gravel(kg/m^3)	617	617	617
Sand(kg/m^3)	986	767	657
Tyre rubber(kg/m^3)	-	219	329
OPC(kg/m^3)	370	370	370
Water(kg/m^3)	195	195	195
W/C	0.53	0.53	0.53
VMA(wt % over P)	0.39	0.39	0.39
SP(wt % over P)	0.84	0.97	1.15

SCC-A is mix with 0% of tyre rubber

SCC-B is mix with 20% of tyre rubber

SCC-C is mix with 30% of tyre rubber

With this experiment we can verify that the self-compacting technology is more fruitful in preparing rubberized concrete than traditional one. The relative strength Sc /Sc0 (Sc and Sc0 being the compressive strengths of rubberized concrete and reference concrete, respectively) is plotted as a function of volume rubber content over the total concrete volume. This behavior can be ascribed to a micro-structural improvement due to the use of self-compacting technology: in fact, the cement matrix, enriched by filler presence, might firmly embed the finest rubber phases, although tyre particles did not previously undergo any surface treatment. Effective adhesion between tyre rubber (Hernandez-Olivares et al, 2002) and cement matrix seems to occur as verified by scanning electron microscopy carried out on the undisturbed fracture surface resulting from compressive test. For SCC-C, a tight microstructure: tyre particle appears well covered by cement matrix, where other tyre residues are evident. The high flow ability and the cohesiveness of the fresh concrete, obtained thanks to the addition of admixtures and fine filler, seem help a strict contact between organic and inorganic phases.

Table 2

Fresh and Mechanical properties of SCC-A, SCC-B, SCC-C

Property	SCC-A	SCC-B	SCC-C
Slump flow test(mm)	650	680	700
Water absorption %	7.5	7.8	8.3

4. CONCLUSIONS

Self-compacting technology seems really suitable for preparing concrete with more versatile mechanical behavior adding large volumes of tyre rubber wastes, even without any surface treatment, in its mix design. The following conclusions can therefore be drawn:

- SCRC requires slightly higher amount of super plasticizer than SCC to reach self-compacting properties, keeping constant water / cement and water /powder weight ratios
- Concrete compressive strength and stiffness decrease with increasing amount of rubber phase in the mix, but the obtained values are higher than those of ordinary Portland cement concretes admixed with similar amounts of tyre rubber wastes
- Significant concrete deformability before failure and capability to withstand post-failure loads with some further deformations are exhibited by SCRC due to the tyre rubber waste presence
- SCRC porosity is only poorly affected by the presence of significant amount of rubber phase in comparison with that of ordinary SCC.

Self-compacting technology seems therefore to be promising to control microstructure of the new SCRC in order to obtain more versatile and innovative mechanical behavior for SCC uses. Of course, these findings are based on the present results and further SCRC formulations are needed to strongly confirm the effective superiority of self-compacting rubberized concrete over plain rubberized concrete reported in literature. Size, origin and amount of tyre rubber particles included in mix design may exert different effects on concrete microstructure: further researches will be focused on the investigation of these aspects as strictly related with physical and mechanical properties of the final product. Moreover, as tyre particles should exhibit insulating behavior typical of rubber materials, SCRC appears very attractive also for the production of noise reducing pavement: investigations in this field are currently running.

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