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Improvement of chloride ion penetration resistance in cement mortars modified with rubber from worn automobile tires

N. Oikonomou *, S. Mavridou

Laboratory of Building Materials, Department of Civil Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

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ABSTRACT

Disposal of worn tires poses a major problem worldwide. In Greece more than 50,000 tons of worn automobile tires are stockpiled annually. This paper presents the results of laboratory research that examines the incorporation of tire rubber granules as a partial replacement for the sand in cement mortars. Physical and mechanical properties of these rubber mixtures are studied while, for the first time, resistance to chloride ion penetration is measured.

Results showed a decrease in mechanical properties, whereas an increase in chloride ion penetration resistance has been observed. This implies that cement-based mortar and concrete products, modified with tire rubber granules as a partial replacement for the sand, can be used in applications where mechanical properties are not of prime importance but where high resistance to chloride ion penetration is demanded.

1. Introduction

In Greece more than 50,000 tons of worn mobile tires are generated annually, and this figure is expected to increase in the coming years along with an expected increase in traffic. Unfortunately a large part of these tires often gets illegally discarded at dumpsites and since tires are not biodegradable, they will remain in landfill with very little degradation over time, presenting a continuing environmental hazard.

Lately law no109/75/2004 is issued concerning the means and the terms for the alternative management of worn tires from automobiles in Greece, in compliance with the European Directive 31/1999, which forbids the deposition of worn tires in landfills by mid-2006. According to this law, land filling of whole worn tires is forbidden since 2004 and by the end of July 2006, no land filling – even for small particles of tires – is permitted. By the 31st of the same month, the utilization of worn tires must reach 65% of total amount of tires and the recycling of these should be at least 10% [1]. Since 2002, in Greece, there is a legislated system called Ecoelastika S.A. [2], which concerns tire management and whose target is the application of laws issued.

Rubber tire can be used in a variety of civil and non-civil engineering applications such as in road construction, in geotechnical works, as a fuel in cement kilns and incineration for production of electricity or as an aggregate in cement-based products. Today in Greece the most common uses of worn tires are as a fuel in cement kilns and in the production of electricity, whereas many studies are being carried out to find a way to include worn tires in products based on cement or asphalt.

The present study concerns the use of different percentages of rubber from worn automobile tires in cement-based products. Some physical and mechanical properties, as well as absorption of water by immersion under vacuum, of cement mortars with the addition of tire rubber have been studied. The tire rubber has been used in powder form to minimize the loss in mechanical properties due to tire rubber incorporation, which has been studied worldwide [3–19].

Meanwhile, for the first time, resistance to chloride ion penetration is measured for all the mixtures and it is found to increase as percentage of tire rubber increases. This increase in resistance has important practical implications, taking into account that penetration of chloride ions into reinforced concrete is the major source of corrosion of embedded reinforcing steel and as a result civil infrastructure based on concrete such as roads; bridges; etc. are threatened [20–22]. Deterioration of such structures is provoked from this kind of penetration. The depth of the reinforcement from the exposed surface, the frequency and duration of its exposure, and the quality of concrete determine the time which is required for the chlorides to reach the embedded steel in sufficient quantities to initiate corrosion [20].

According to the results of this study such rubber mixtures can be used in applications where there is a need for low chloride ion penetration and in structures where corrosion of reinforcement must be avoided. Similar results, as far as durability of concrete

* Corresponding author. Tel./fax: +30 2310 995655.
E-mail address: ikonomou@civil.auth.gr (N. Oikonomou).

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is concerned, have been obtained when fine glass powder has been used as a substitute for cement in concrete [23].

2. Experimental work

In the present study cement – IV/B 32.5N, normalized siliceous (standard) sand [24], and granulated tire rubber were used in order to manufacture the series compositions. Granulated tire rubber, which is a fine material with gradation close to that of the sand, has been generated from the mechanical shredding of rubber waste and was supplied by a Greek company [25]. Sieve analysis of tire rubber used is presented in Fig. 1, whereas sand mixed with tire rubber is illustrated in Fig. 2.

For the control specimens (TR0), cement, normal sand and water were used. For all mortar mixtures, the flow table extension were kept constant at 11 ± 1 cm. Tire rubber was substituted for sand at 2.5 wt%, 5 wt%, 7.5 wt%, 10 wt%, 12.5 wt% and 15 wt%. For the percentage with the lowest value of charge passed, which was 12.5%, more mixtures were produced by the use of commercial additives: a super plasticizer (SP), a 60% anionic bitumen emulsion (BE) and a SBR latex (L). These additives were chosen based on a previous experimental study of the authors where it had been concluded that these additives improve mechanical and physical properties of rubberized cement mortars [12]. Coincidently, according to several studies latex modified concrete proved to be superior in its corrosion resistance compared to the conventional one [10,21,22]. For all the compositions, apart from the control one and the ones with tire rubber in percentages more than 10.0%, cement and water contents were kept constant, while the content of tire rubber and sand changed. Table 1 summarizes the characteristics and proportions of the materials used in the specimen's preparation.

The mortar specimens were moist cured for 28 d at 20 ± 2 °C and >95% relative humidity after demolding. Specific weight, compressive and flexural strength, dynamic modulus of elasticity and absorption of water by immersion under vacuum were studied on $4 \times 4 \times 16$ mm in size mortar specimens while for the measurement of the resistance to chloride ion penetration, cylindrical specimens with a diameter of 100 mm and 50 mm long were examined. All tests were conducted according to standards [24–27]. Especially for the measurement of absorption of water by immersion under vacuum, RILEM TC 14 CPC 11.3 standard has been used. Specimens were put into a tank under vacuum for at least 2 h and then water has been transferred from its initial tank into the one in which the specimens were placed and after 24 h the mass of the wet specimens has been measured. The difference between the two values (the initial mass before wetting and the wet mass) divided by the initial mass gives a measure of the absorption of water by immersion under vacuum (%). Results of specific weight,

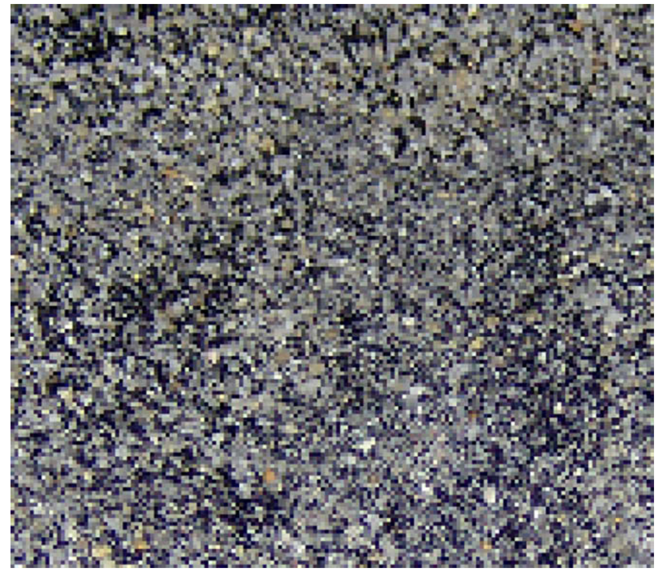

Fig. 2. Sand and tire rubber mixture.

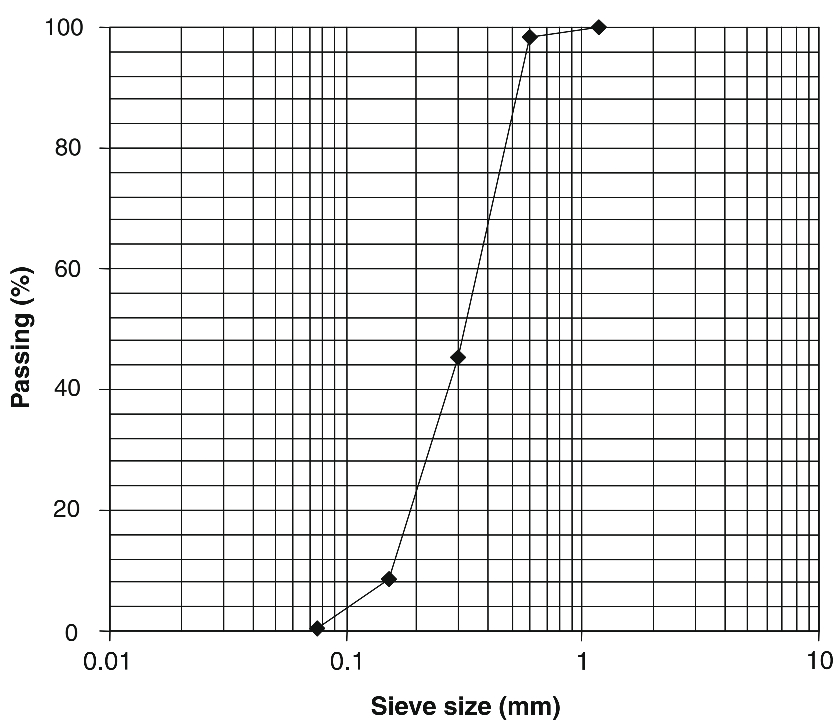

Fig. 1. Sieve analysis of tire rubber.

Table 1
Mixture proportions.

Materials	Mixture						
	TR0	TR2.5	TR5.0	TR7.5	TR10.0	TR12.5	TR15.0
Cement IV/B 32.5N (g)	450.0	450.0	450.0	450.0	450.0	450.0	450.0
Standard Sand (g)	1350.0	1316.3	1282.5	1248.8	1215.0	1181.3	1147.5
Tire rubber (g)	0	33.8	67.5	101.3	135.0	168.8	202.5
Tire rubber (wt% of sand)	0	2.5	5.0	7.5	10.0	12.5	15.0
Water (g)	225.0	225.0	225.0	225.0	225.0	235.0	245.0
Flow test (cm)	12.0	11.3	10.8	10.5	10.1	10.0	10.0

	TR0-SP1.0	TR12.5-SP1.0	TR0-L5.0	TR12.5-L5.0	TR0-BE5.0	TR12.5-BE5.0
Cement IV/B 32.5N (g)	450.0	450.0	450.0	450.0	450.0	450.0
Standard Sand (g)	1350.0	1181.3	1350.0	1181.3	1181.3	1181.3
Tire rubber (g)	0	168.8	0	168.8	0	168.8
Tire rubber (wt% of sand)	0	12.5	0	12.5	0	12.5
Additive	SP	SP	Latex	Latex	BE	BE
Additive, (g)	4.5	4.5	22.5	22.5	22.5	22.5
Additive (wt% of cement)	1.0	1.0	5.0	5.0	5.0	5.0
Water (g)	200.0	200.0	216.0	216.0	216.0	216.0
Flow test (cm)	11.7	10.0	11.5	10.0	11.5	10.0

Explanation of symbols: TR0, control mortar; TR2.5, 2.5% tire rubber; TR0-SP1.0, control mortar + superplastisizer 1.0%; TR5.0, 5.0% tire rubber; TR12.5-SP1.0, 12.5% tire rubber + superplastisizer 1.0%; TR7.5, 7.5% tire rubber; TR0-L5.0, control mortar + Latex 5.0%; TR10.0, 10.0%; TR12.5-L5.0, 12.5% tire rubber + Latex 5.0%; TR12.5, 12.5% tire rubber; TR0-BE5.0, control mortar + bitumen emulsion 5.0%; TR15.0, 15.0% tire rubber; TR12.5-BE5.0, 12.5% tire rubber + bitumen emulsion 5.0%.

Table 2
Mechanical properties and absorption of water by immersion under vacuum of rubber mixtures.

Characteristics	Mixture						
	TR0	TR2.5	TR5.0	TR7.5	TR10.0	TR12.5	TR15.0
Specific weight, (g/cm^3)	2.23	2.11	2.03	1.94	1.84	1.76	1.68
Compressive strength, (MPa)	40.75	30.92	21.33	16.15	11.12	9.70	8.60
Flexural strength, (MPa)	9.00	7.50	5.70	5.25	4.30	3.50	2.90
Absorption of water by immersion under vacuum (%)	8.81	8.25	7.37	7.25	7.03	6.87	6.79

	TR0-SP1.0	TR12.5-SP1.0	TR0-L5.0	TR12.5-L5.0	TR0-BE5.0	TR12.5-BE5.0
Specific weight (g/cm^3)	2.26	1.79	2.18	1.70	2.21	1.75
Dynamic modulus of elasticity (GPa)	42.48	15.37	35.20	11.38	39.53	13.47
Compressive strength (MPa)	43.70	13.68	35.83	8.95	42.89	12.79
Flexural strength (MPa)	10.26	4.50	8.36	3.20	10.11	4.10
Absorption of water by immersion under vacuum (%)	7.91	6.25	6.79	4.92	6.96	5.01

mechanical properties and absorption of water by immersion under vacuum of the compositions examined are showed in Table 2.

3. Electrical indication of resistance to chloride ion penetration

All specimens were tested for chloride ion penetration resistance according to specifications [27] at the age of 28 d. The PROOVE'it Rapid Chloride Permeability Tester of German Instruments has been used for this purpose. The amount of electrical current passed through 50 mm thick slices of 100 mm nominal diameter cylinders was measured over a period of 6 h. A potential difference of 60 V dc was maintained across the ends of the specimen, one of which was immersed in a sodium chloride (3% NaCl) solution while the other one in a sodium hydroxide (0.3 N NaOH) solution. The total charge passed, in coulombs (which is related to the resistance of the specimen to chloride ion penetration) was measured. The results of these tests are listed in Table 3 whereas the test device is showed in Fig. 3.

Table 3
Chloride ion penetrability based on charge passed.

Composition	Charge passed (Coulombs)
TR0	6103
TR2.5	5235
TR5.0	5080
TR7.5	4551
TR10.0	4257
TR12.5	3956
TR15.0	3915
TR0-SP1.0	5910
TR12.5-SP1.0	3640
TR0-L5.0	5334
TR12.5-L5.0	2824
TR0-BE5.0	5208
TR12.5-BE5.0	2692

4. Results and discussion

For all the mixtures modified with tire rubber, workability decreased with increasing tire rubber content as shown in Table 1. Granulated rubber has a lower specific weight than the sand and as a result mortars modified with tire rubber showed smaller specific weights than the control mortar. According to the literature [3–19] the use of tire rubber in products based on cement causes a decrease in mechanical properties which can be noticed in the present study, as well. Especially, as shown in Table 2, percentage of tire rubber powder affected compressive strength more than flexural strength.

As seen in Table 2, all specimens showed a decrease in dynamic modulus of elasticity, which is due in part to the nature of the rubber, which favors the absorption of ultrasonic waves. This

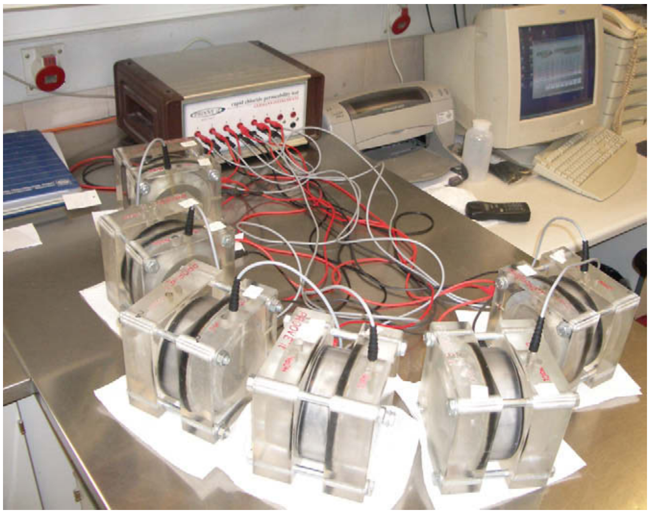

Fig. 3. PROOVE' it Rapid Chloride Permeability Tester for the Measurement of Chloride Ion Penetration.

reduction in elastic modulus indicates higher flexibility, which can be viewed as a positive gain in rubberized concrete mixtures used in stabilized base layers in flexible pavements.

Measurement of absorption of water by immersion under vacuum showed that the addition of rubber particles decreases absorption of water by immersion under vacuum of the matrix. Similar results have been obtained in previous investigations on such rubberized mixtures [12,18].

Regarding resistance to chloride ion penetration, it is enhanced by the introduction of granulated tire rubber in cement mortars (Table 3). As the results show, penetration of chloride ions decreases as rubber content increases. This reduction ranges from 14.22% to 35.85% for compositions TR2.5 and TR15.0, respectively. It must be noted that the compositions TR12.5 and TR15.0 showed almost similar values of charge passed. For this reason, 12.5% has been chosen as the optimum percentage of tire rubber for further examination, with the use of additives, which were found to increase mechanical strengths of rubberized mortars. For those mixtures, a superplastisizer, latex and an anionic bitumen emulsion have been added to cement mortars, improving further their chloride ion penetration resistance. Moreover, mixtures with tire rubber and additives exhibited improved penetration resistance compared to control mortars with the same additives alone (with no tire rubber).

Furthermore, the mixture with 12.5% tire rubber per weight of the sand and with the addition of bitumen emulsion gave the best results, which was a reduction of chloride ion penetration up to 55.89% compared to the control mixture (TR0). The same mixture demonstrated also the best mechanical properties compared to SP and to PL for the same amount of tire rubber.

5. Conclusions

In the present study physical and mechanical properties of cement mortars modified with worn tires from automobiles have been investigated. In parallel for the first time, chloride ion penetration in such mixtures was measured. Granulated tire rubber was substituted for sand in different weight percentages; additives such as superplastisizer, a 60% anionic bitumen emulsion and SBR latex were used in some of the mixtures, since they have been found to improve mechanical and physical characteristics of the mortars. Although strength reduction is certainly a negative property that may hinder the use of tire rubber in cement-based products, we observed positive effects on some other properties, such as absorption of water by immersion under vacuum and resistance to chloride ion penetration. Especially, the reduction in chloride ion penetration in cement mortars and in concrete reduces the potential for corrosion of embedded reinforcement, which is of great practical importance.

Concrete modified with tire rubber concrete can be advantageous for special applications where the main request is not for mechanical properties, such as in the production of sound barriers and cement blocks, as lightweight concrete walls, as well as in structures exposed to aggressive environments where high resistance to chloride ions penetration is required. Regarding the last of these application areas, additional research is needed to understand the performance of granulated rubber concretes under more realistic environmental exposure conditions, such as those involving wet–dry cycling.

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