Research Article ISSN 2832-9384

Journal of Materials and Polymer Science

Durability and Recycling of Rubber Concrete

C. Paglia*, M. Paderi

Institute of Materials and Construction, Supsi, V. Flora Ruchat 15, CH-6850 Mendrisio, Switzerland.

***Corresponding author**

C. Paglia,
Institute of Materials and Construction,
Supsi, V. Flora Ruchat 15,
CH-6850 Mendrisio,
Switzerland.
ORCID : https://www.researchgate.net/profile/C-Paglia

Submitted : 18 Apr 2024 ; Published : 13 May 2024

Citation: Paglia, C. & Paderi, M. (2024). Durability and Recycling of Rubber Concrete, J mate poly sci, 4(2) :1-5.
DOI : https://doi.org/10.47485/2832-9384.1054

Abstract

The addition of crumb rubber particles causes a decrease in the compressive strength of concrete. This is particularly observed beyond 3.6% crumb rubber addition with respect to the total weight of the aggregates. The accelerated carbonation also indicates an increase in the CO_2 ingress, which is partially due to the low quality of the interface rubber particles-cementitious matrix. On the other hand, the water sealant properties, the chloride penetration resistance and the resistance to freeze and thaw exhibit an increase. This latter feature is mainly due to the implemented ductility of the crumb rubber concrete, which can better adapt to the thermal stress that arises during the freezing action. Furthermore, the addition of recycled crumb rubber up to 25% of the aggregate weight to concrete positively affect the mechanical as well as the durability performance.

Keywords: concrete, rubber, strength, durability, recycling.

Introduction

The combination of materials with concrete is a widely investigated topic. A main issue is the addition of polymer-based compounds or waste within the cementitious materials. The wide difference in the density and material properties increase some difficulties regarding the general features of these composite materials. The high amount of waste tire is a main issue. Recycling methods of tires exist (European Commission, 2020), although the vulcanization process requires heat and is not reversible. Waste tires are sometimes landfilled or even open burnt or used as alternative fuels for cement kilns ((Nehdi & Khan, 2001). Rubber aggregates can be produced in form of shredded, crumb, granulate and fibres at room or cryogenic temperatures (Topcu & Unverdi, 2018). The rubber concrete is investigated since decades. However, the different nature of the organic particles, such as the crumb rubber, especially the low modulus of elasticity and the mineral cement as well as the rocky components decreases the compressive strength and the rigidity (Eldin & Senouci, 1993). This fact may also be due to the reduced adhesion between the rubber particles and the cementitious component (Issa & Salem, 2013). Conversely, the softer behaviour of the rubber particulates may lower the crack propagation and enhance the energy adsorption capability and the ductility of the concrete (El-Dieb, et al., 2001). The interparticle friction may reduce the workability of the mixtures in the fresh state, in particular at a high rubber dosage (Khatib & Bayomy, 1999) and influence the future properties in the hardened state.

All the above factors exhibit an influence on the durability. The abrasion resistance tends to increase (Kang et al., 2012). The freeze and thaw resistance appears to be implemented with the addition of the crumb rubber particles (Topcu & Demir, 2007), although the influence of the rubber dosage is not completely clear. The chloride diffusion coefficient seems to increase with the addition of crumb rubber particles, but it is not linearly correlated with the dosage. The carbonation depth appears to increase with the dosage and the particle size due to the low quality of the interface cement-based matrix and rubber particles (Bravo & Brito, 2012). However, the main durability factors require further investigation, in particular when the rubber concrete is recycled.

The aim of the work is to further characterize the properties of crumb rubber concrete with respect to the strength and the main durability parameters, especially by adding a recycled rubber concrete. This latter component is derived from the crushing of the same produced rubber concrete and was added up to 25% of the total aggregate weight.

Experimental Procedure

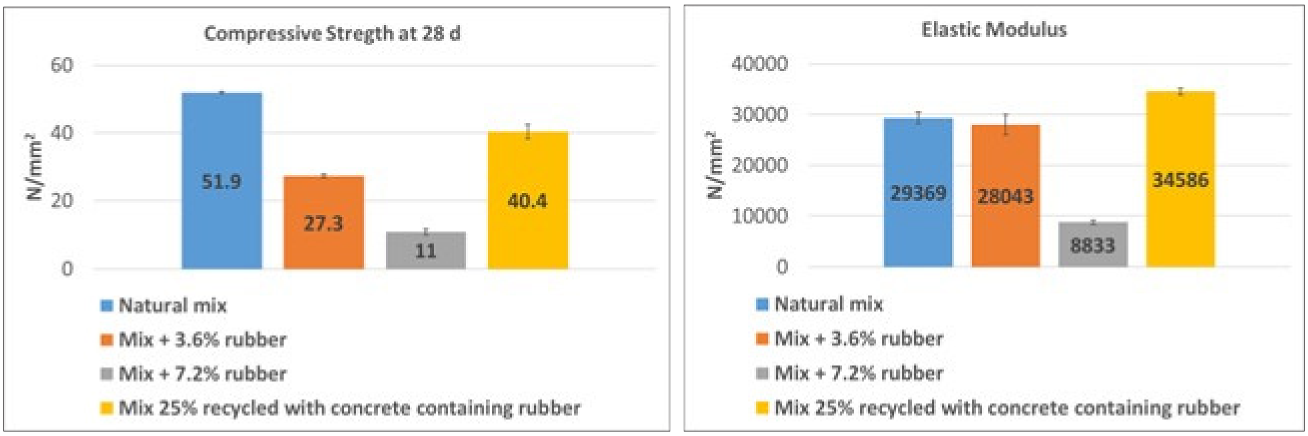
The reference concrete CPN C with a compressive strength class C 25/ 30 was mixed by using a CEM I 42.5 N with a dosage of 320 kg/m^3. The water content ranged from 153 liters to 171 liters, in order to achieve the desired workability. The crumb rubber particles were added with a dosage of 70 kg/m^3 (3.6% of total aggregate weight) and 140 kg/m^3 (7.2% of total aggregate weight). The fly ash addition was 20 kg/m^3 and the superplasticizer 0.9% by cement weight. Furthermore, a blend was prepared with the addition of 25% by weight of total aggregate with an average dosage of 105 kg/m3 (Table 1). The recycled crumb rubber concrete aggregates were prepared by crushing both rubber concrete with 70 kg/m^3 and 140 kg/m^3 rubber content and mixing them to produce the recycled rubber concrete mix. The compressive strength and the durability properties (SN 505 262/1 - Concrete Structures - Supplementary specifications, Zurich, 2019) were measured according to the European standards (European standard EN 206:2013 +A2:2021. Concrete: specification, performance, production and conformity, 2021).

Natural CPN C mix		CPN C mix + rubber 70 Kg/m^3		CPN C mix + rubber 140 Kg/m^3		CPN C mix +25% recycled with concrete containing rubber (105 Kg/m^3)	
CEM I 42.5 N Normo 4	320 Kg	CEM I 42.5 N Normo 4	320 Kg	CEM I 42.5 N Normo 4	320 Kg	CEM I 42.5 N Normo 4	320 Kg
Water content	153	Water content	153	Water content	171	Water content	171
Aggregates (0/32)	1960 Kg	Aggregates (0/32)	1960 Kg + 70 Kg rubber	Aggregates (0/32)	1960 Kg + 140 Kg rubber	Aggregates (0/32)	1470 Kg (N) + 490 Kg (Rec. concrete containing rubber)
Fly ash	20 Kg	Fly ash	20 Kg	Fly ash	20 Kg	Fly ash	20 Kg
BASF 155	0.9% (mass cem.)	BASF 155	0.9% (mass cem.)	BASF 155	0.9% (mass cem.)	BASF 155	0.9% (mass cem.)
Aggregates absorption	15	Aggregates absorption	15	Aggregates absorption	15	Aggregates absorption	15

Table 1: Concrete mix proportions.

Results and Discussion

The compressive strength of the concrete with natural aggregates exhibits a mean value of 51.9 MPa after 28 days of hydration. The addition of crumb rubber to 3.6% and 7.2% by weight exhibits a lowering of the strength down to 27.3 Mpa and 11.0 Mpa respectively. A significant reduction is observed beyond the crumb rubber dosage of 3.6%. On the other hand, the replacement of the total aggregate with 25% weight of recycled crumb rubber concrete maintains the strength mean value at 40.4 MPa (Fig. 1 left). Similarly, the modulus of elasticity, decreases with respect to the reference natural mix from a mean value of 29’369 MPa to 28’043 MPa for the 3.6% rubber addition and to 8’833 MPa with a 7.2% rubber addition. Conversely, the addition of recycled crumb rubber concrete slightly increases the stiffness up to 34’586 MPa (Fig. 1 right). A dosage above 3.5 % of rubber soften the cementitious composite material due to the high elastic behaviour of the rubber (Eldin & Senouci, 1993).



Figugure 1 : Compressive strength (left) and elastic modulus (right) of the blends.

The durability of the blends exhibits variable results. The addition of crumb rubber adversely affects the accelerated carbonation from 4.6 mm √year from the reference concrete to 13.3 mm √year for the 7.2% rubber concrete. The addition of recycled crumb rubber concrete to 25% limits the carbonation to 4.8 mm √year close the reference concrete with natural aggregates (Fig. 2 left). The chloride penetration exhibits a slight increase up to 15.9 x 10^{-12} m^2/s mean value, while the replacement of 25% with recycled aggregates decreases the chloride penetration to 6.8 x 10^{-12} m^2/s (Fig. 2 right). In this concern, the binding capacity of the old hydrated cement paste seems to contribute to the increased penetration resistance. Conversely, the addition of 7.2 % crumb rubber does not allow to maintain a sufficient integrity of the specimens to be tested with reliable results. It must also be stated that, all specimens show a relatively high chloride penetration beyond 10x10^{-12} m^2/s, which may limit the use for durable infrastructure concrete, except when the recycled crumb rubber concrete component is added.

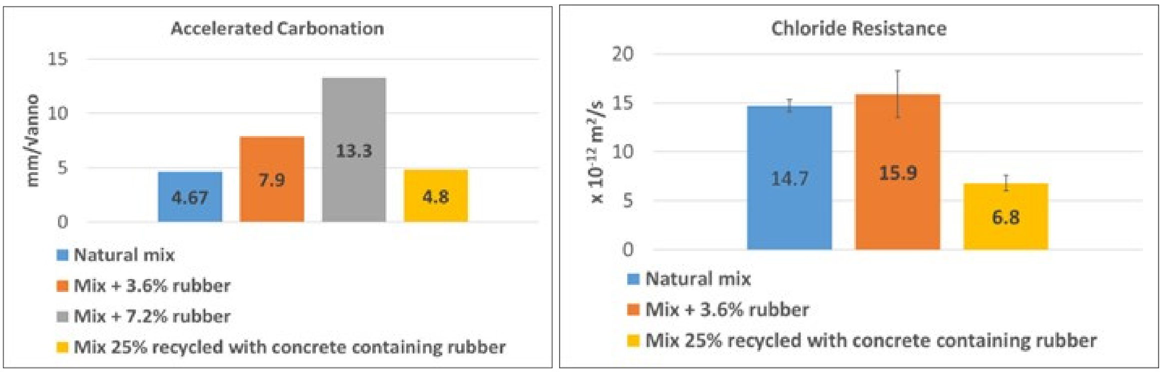


Figure 2: Accelerated carbonation (left) and chloride penetration (right) of the blends.

Despite the variable measurements that must be considered for the accelerated freeze / thaw resistance tests, the resistance to the freezing action measured by the scaling concrete mass from the surface shows a slight decrease with the 3.6% rubber concrete. Beyond this value, the resistance is increased for the 7.2% rubber addition and for the recycled rubber concrete (Fig. 3 left). This fact indicates that starting from a crumb rubber dosage of 3.6%, the ductility of the specimens in significantly increased and the stress present during the thermal excursions can be better accommodated. Therefore, the increase in the ductility cannot only be exploited in the high impact adsorbing energy6, but also against the freezing action. Nonetheless, the crumb rubber or the recycled component dosage must be optimized, in order to achieve general reasonable strength and durability. The water permeability indicates mean values above 10 g/m^2s for the reference and the specimens with the addition of 7.2 % crumb rubber. These concretes may not be considered as water proofing concrete. The concretes with less crumb rubber particles, namely 3.6 %, and with the addition of recycled rubber concrete exhibit a water permeability below the reference concrete and can be considered as water sealant.

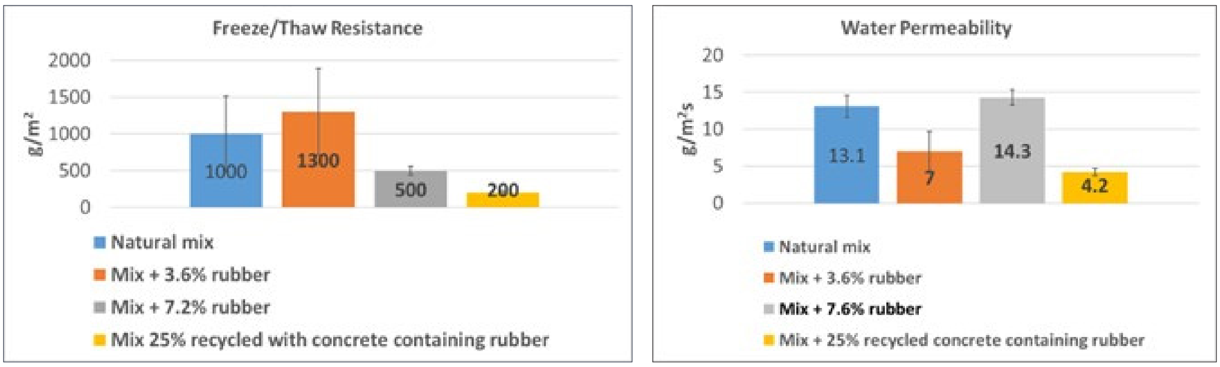


Figure 3: Accelerated freeze thaw resistance (left) and water permeability (right).

The total porosity does not show a relevant change in the values (Fig. 4 left). Contrarily, the compressive strength significantly varies between concretes. This fact accounts for the relative importance of the interface adhesion and microstructural dishomogeneity in these zones. The saturable porosity slightly decreases as compared to the reference concrete (Fig. 4 right). This may be correlated with the water permability along with the quality of the rubber-cementitious matrix interface. On the other hand, the non-saturable porosity exhibits slightly higher values up to 4% for the 7.2% rubber concrete as compared to the referrence with 3.1%, while the concrete with 25% recycled component addition exhibits 3.0%. The saturable porosity partially correlates with the chloride penetration and the freeze / thaw resistance, altough not always directly. Conversely, the higher accelerated carbonation of the crumb rubber concrete, except for the concrete with the recycled component, may indicate the high influence of the low quality rubber-hydrated cement matrix interface (Bravo & Brito, 2012) with respect to CO_2 ingress.

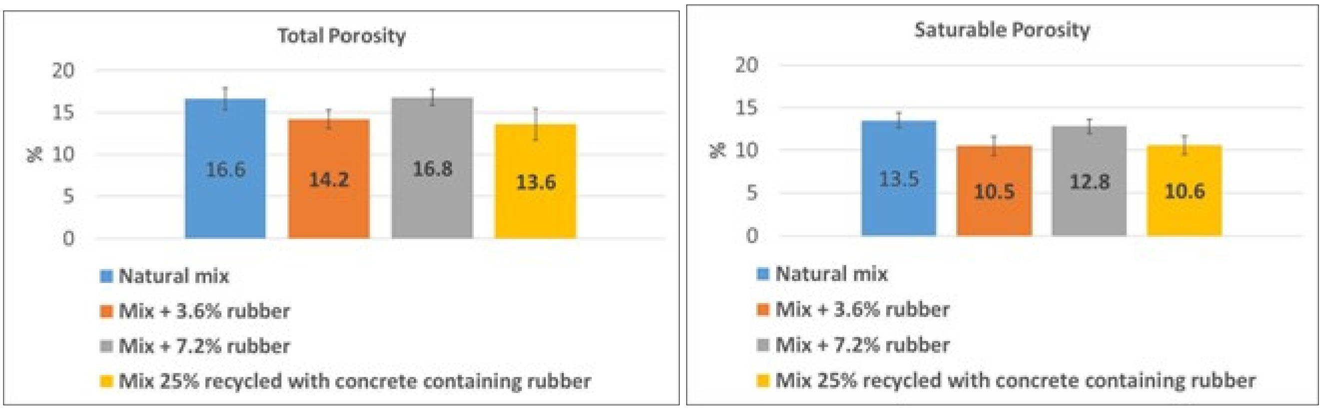


Figure 4: Total (left) and saturable porosity (right) of the blends.

The microstructure exhibits a local low quality of the cement-based matrix along the the crumb rubber particles interface with cracks and porosity as well as some detachments (Fig. 5 left). Additionally, a homogeneous mixing of the crumb rubber particles is not always accomplished and some local concentrations may be observed (Fig. 5 right). Furthermore, some crumb rubber particles may show a relatively smooth surface, which further lowers the adhesion to the cementitious matrix.

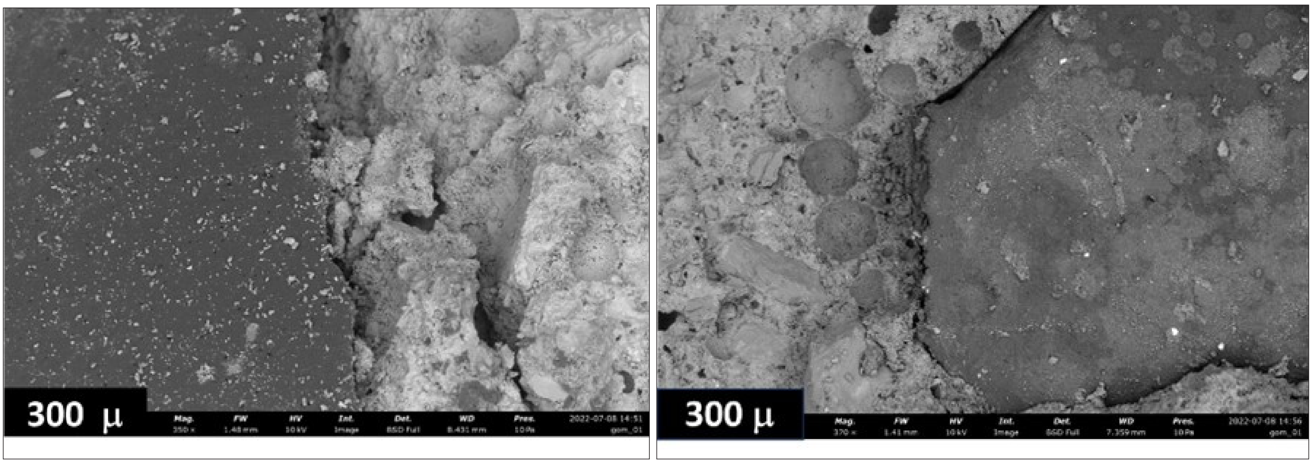


Figure 5: Microstructure of the interface crumb rubber particle and cementitious matrix (left) and local particle concentration (right).

Conclusions

The addition of crumb rubber particle tends to decrease the mechanical properties. The resistance to the chloride penetration may increase with the rubber particle addition, in particular when a recycled rubber concrete component of 25% is added to the concrete. The increase in the resistance is seen for the freeze and thaw tests, where the recycled rubber concrete and the high addition of rubber increase the ductility of the specimens with respect to the thermal stress accommodation during the accelerated tests. The carbonation is negatively affected by the crumb rubber addition due to low quality interfaces. The dosage of the crumb rubber and the quality of the rubber-cement matrix interface may largely control the concrete durability parameters, while the addition of the 25% recycled component positively affect the durability as well as the mechanical performance.

Acknowledgements

A special thanks to the technicians of the Institute of materials and construction, Supsi.

References

1. European Commission. (2020). Cordis Horizon 2020. Innovative and compact process for recycling rubber suitable to improve the environmental footprint of the tyre industry over the life-cycle. Rew-Tyres Grant agreement ID: 733676, 30 September 2019. DOI: https://doi.org/10.3030/733676
2. Nehdi, M. & Khan, A. (2001). Cementitious composites containing recycled tire rubber: an overview of engineering properties and potential applications. *Cement concrete aggregates, 23*(1), 3-10. DOI: http://dx.doi.org/10.1520/CCA10519J
3. Topcu, I. B. & Unverdi, A. (2018). Scarp tires / crumb rubber. In R. Siddique, & P. Cachim. Waste and supplementary cementitious materials in concrete, Characterisation, properties and applications, Woodhead Publishing, 51-77. Retrieved from https://shop.elsevier.com/books/waste-and-supplementary-cementitious-materials-in-concrete/siddique/978-0-08-102156-9

4. Eldin, N. N. & Senouci, A. B., (1993). Rubber tire particles as concrete aggregate. *Journal of materials in civil engineering, 5*(4), 478-496. DOI: https://doi.org/10.1061/(ASCE)0899-1561(1993)5:4(478)
5. Issa, C. A. & Salem, G., (2013). Utilization of recycled crumb rubber as fine aggregates in concrete mix design. *Construction and building materials*, 42, pp. 48-52. DOI:http://dx.doi.org/10.1016/j.conbuildmat.2012.12.054
6. El-Dieb, A. S., Abdel-Wahab, M. M. & Abdel-Hameed, M. E., (2001). Concrete using tire rubber particles as aggregate. In Dhir R. K. et al., (Eds). Recycling and use of used tires, Thomas Telford, London. Retrieved from https://trid.trb.org/view/687246
7. Khatib, A. K. & Bayomy, F. M., (1999). Rubberized Portland cement concrete, *Journal of materials in civil engineering, 11*(3), pp. 206-213. Retrieved from https://trid.trb.org/View/505947
8. Kang, J., Zhang, B. & Li, G. (2012). The abrasion-resistance investigation of rubberized concrete. Journal Wuhan University Technol. *Mater. Sci., 27*(6), pp. 1144-1148. Retrieved from https://link.springer.com/article/10.1007/s11595-012-0619-8
9. Topcu, I. B. & Demir, A., (2007). Durability of rubberized mortar and concrete. *Journal of materials in civil engineering, 19*(2), 173-178. DOI: http://dx.doi.org/10.1061/(ASCE)0899-1561(2007)19:2(173)
10. Bravo, M. & Brito, J. (2012). Concrete made with used tyre aggregate: durability-related performance. *Journal of cleaner production, 25*, 42-50. DOI: https://doi.org/10.1016/j.jclepro.2011.11.066
11. SN 505 262/1 - Concrete Structures - Supplementary specifications, Zurich. 2019.
12. European standard EN 206:2013 +A2:2021. (2021). Concrete: specification, performance, production and conformity. Retrieved from https://standards.iteh.ai/catalog/standards/cen/4f3d2008-978a-47ec-bc12-5660aa40e04d/en-206-2013a2-2021#:~:text=CEN%2FTC%20104-,Concrete%20%2D%20Specification%2C%20performance%2C%20production%20and%20conformity,buildings%20and%20civil%20engineering%20structures