



Influence of NaOH treatment of rubber aggregates on the durability properties of rubberized mortars

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Abstract

The work presented in this paper aims to study the durability of mortars, in which part of the sand has been replaced with rubber aggregates from used tires and have undergone a surface treatment with a sodium hydroxide solution (NaOH). The substitution rates studied are 10%, 17.5%, and 25%. The results are compared with ordinary mortar and mortars with untreated rubber aggregates while samples with the same substitution rates were used. To do this, the following properties have been studied: compressive strength, flexural tensile strength, water absorption by capillarity, water absorption by total immersion, water-accessible porosity, water permeability, and resistance to the chemical degradation by sulfuric acid H₂SO₄.

The results obtained show that the treatment of rubber aggregates by the solution method (NaOH) presented a considerable improvement in mechanical performance (increase in compressive strength and flexural tensile strength) and better durability compared to reference mortar and mortar with untreated rubber granulate.

Key words: mortar, aggregate, rubber, tires, durability, surface treatment, sodium hydroxide solution (NaOH)

1 Introduction

The massive use of concrete exerts considerable pressure on natural resources, leading to intensive exploitation of quarry aggregates, with the consequences of risk of depletion of these resources and environmental problems (destruction of fauna and flora, pollution of groundwater, etc.). Thus and in order to remedy this problem, the Algerian authorities have tightened the conditions for opening new quarries, as well as the promulgation of increasingly drastic laws for the protection of the environment. Therefore, it is necessary to look for new sources of aggregate supply. Moreover, the accumulation of waste such as used tires becomes more and more uncontrollable and occupies a significant public space. According to their compositions, tires are classified as non-dangerous and non-degradable waste (approximately 400 years), but due to the risk of uncontrollable fires in landfills because of toxic fumes given

off, the stagnation of water in these places, as well as insects, their valorization seems to be an obligation rather than a choice [1,2].

Anterior studies on the incorporation of rubber aggregates from used tires into cementitious materials have shown better toughness, better impact resistance [3,4], and also better thermal and sound insulation properties than ordinary cementitious materials [5]. On the other hand, they observed drops in the mechanical resistances [6,7].

Among the causes of this decreased resistance is low adhesion between the rubber aggregate and cement paste. For this, much research has been carried out to improve the performance of cementitious materials incorporating rubber aggregates by a surface treatment. Among the surface treatment methods used for rubber aggregates, there is the treatment method with the alkaline solution of sodium hydroxide (NaOH).

Several studies on the influence of this treatment method on the performance of cementitious materials were already carried out. Marques et al. [8] in their study on the Influence of the surface treatment with NaOH solution of rubber aggregates on the properties of mortars found that this method of treatment did not show a significant improvement. Compared to mortars with untreated aggregates, mortars with treated rubber aggregates showed a slight decrease in workability and water absorption. On the other hand, the mechanical properties (compressive strength, tensile strength, and modulus of elasticity) of mortars with untreated rubber granulate showed better results than those treated.

In addition, Iman Mohammadi et al. [9] studied the influence of the treatment of rubber aggregates on the mechanical properties of concrete. They noticed that using this treatment method resulted in notable improvement for the compressive strength, and moderate enhancement in the flexural strength. Qingwen and Jinchao [10] observed the same remark. They used different kinds of rubber aggregate (rubber powder 28 meshes, colloidal particle 0.1-5mm and colloidal particle 2-8mm). They found that the compressive strength and bending strength of rubber concrete improved after soaking in NaOH solution, and the growth rate was related to particle size (the growth rate increases with the decrease in the size of particles).

Ruizhe et al. [11] studied the effect of the treatment of rubber aggregates with NaOH on the properties of self-compacting concrete (fresh state and in the hardened state). They noticed that this method of treatment slightly decreased the workability, expansion, drying shrinkage and improved the compressive and the splitting tensile strength compared to self-compacting concrete with untreated rubber aggregates.

Most of these studies are focused on the influence of treatment with NaOH solution on the improvement of mechanical characteristics and only several studies on the influence of this method on the durability of cementitious materials.

The purpose of this work is to study the effect of incorporating rubber aggregates treated with the alkaline solution of sodium hydroxide (NaOH) on the durability of the mortar. We were interested in the mechanical aspect (compressive strength and flexural tensile strength) as well as the most decisive indicators of durability, namely: absorption by capillarity, water

absorption by total immersion, porosity, permeability to water, and resistance to chemical attack by sulfuric acid H_2SO_4 .

2 Materials and experimental procedures

2.1 Materials

Cement: a CEM II-A with strength class 42.5 was used, manufactured according to the Algerian standard NA 442-2008 [12]. The absolute density and apparent density of the cement were 3.11 g/cm^3 and 1.09 g/cm^3 respectively. A specific surface area was $3371 \text{ cm}^2/\text{g}$ and with the chemical composition as presented in Table 1.

Sand: the class 0/3 of natural sand from the Tebessa region (Algeria) was used, the absolute density and apparent density of the sand were 2.56 g/cm^3 and 1.6 g/cm^3 respectively, and the fineness modulus was 2.26.

Rubber granulate: comes from the mechanical grinding of used tires, the maximum dimension of which was 2 mm (Figure 1), and the absolute density and apparent density were 0.87 g/cm^3 and 0.47 g/cm^3 respectively.

Superplasticizer: The superplasticizer used in the mortar mixtures is an Algerian superplasticizer based on Ether Polycarboxylate, commercially named POLYFLOW SR 3600.

Sodium hydroxide: Also called caustic soda, Chemical Formula: $NaOH$ of U.E origin and packaged by the Algerian company PROCHIMA-SIGMA. In the form of white pearls. Melting point: 318.4°C and-Boiling point: 1393°C . PH: 13-14 (0.5% solenoid).

Sulfuric acid (H_2SO_4): the sulfuric acid used is from Sigma-Aldrich Chemie GmbH Company – Germany. In liquid form, colorless, odorless, pH 0.3 at 49 g/l at 25°C and their density was 1.84 g/cm^3 .

Table 1: Chemical composition of the cement CPJ-CEM II/A

Compounds	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	Na ₂ O	SO ₃	PAF	MnO
(%)	58.6	24.9	6.6	3.6	1.2	0.8	0.08	2.2	1.7	--

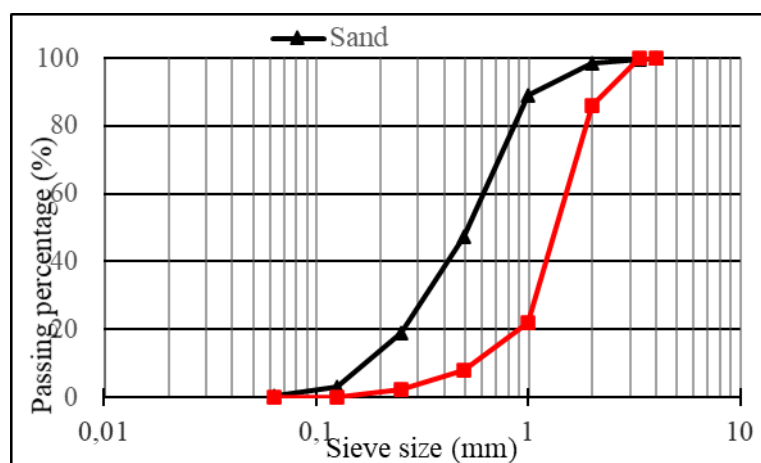


Figure 1: Sieve analysis for sand and rubber used.



Figure 2: Rubber aggregate used

2.2 Experimental program

2.2.1 Mix design

Test specimens of mortar were prepared according to the standard EN196-1 [13]. The same W/C ratio of 0.5 was fixed for all mixes. The superplasticizer dosage is 1.5% of the cement weight.

We are prepared two series of mortars. The first series with untreated rubber aggregate and the substitution percentages of 10%, 17.5% and 25% (RM10%, RM17.5%, and RM25% successively) by volume of sand, the second series with treated rubber aggregate and with the same percentage of substitution (RMT10%, RMT17.5%, and RMT25% successively) and reference mortar (M) (0% rubber aggregate) was used as a reference.

The different compositions of the mortars are grouped in Table 3.

Table 3: Mortars mix constituents

	M	RM10%	RM17.5%	RM25%	RMT10%	RMT17.5%	RMT25%
<i>Cement (kg/m³)</i>	500.0	500.0	500.0	500.0	500.0	500.0	500.0
<i>Sand (kg/m³)</i>	1500.0	1350.0	1237.5	1125.0	1350.0	1237.50	1125.0
<i>Rubber (kg/m³)</i>	--	52.2	91.4	130.5	52.2	91.4	130.5
<i>Water (kg/m³)</i>	250.0	250.0	250.0	250.0	250.0	250.0	250.0
<i>Superplasticizer (%)</i>	1.5	1.5	1.5	1.5	1.5	1.5	1.5

For the treatment of rubber aggregates with NaOH:

- The rubber aggregate is immersed in NaOH solution (prepared from the dissolution of 10 g of sodium hydroxide NaOH in 90 cm³ of distilled water) for 30 minutes.
- After 30 min of immersion, rinsing with distilled water follows to remove all the soda adsorbed on the surface of the rubber aggregates. To ensure that all the soda has been removed from the rubber aggregates, the pH of the solution is tested until this pH is equal to 7.
- The rubber aggregates are dried in the open air before use [14].

2.2.2 Testing methods

The tests carried out on the different formulations are:

- Compressive strength and flexural tensile strength on specimens of size $(40 \times 40 \times 160)$ mm³ in accordance with standard EN 196-1 [13]. These tests were studied at the age of 14 and 28 days.
- Capillary water absorption test, water absorption test by total immersion, and porosity test were carried out on specimens of size $(40 \times 40 \times 160)$ mm³ in accordance with standard NF EN 480-5 [15], standard NBN B15-215 [16], and standard EN18-459 [17] respectively.
- Water permeability tests (based on the depth of penetration of water under pressure), were carried out on specimens of size $(150 \times 150 \times 150)$ mm³ in accordance with standard NF EN 12390-8 [18]. To determine diffusion depth into specimens after water penetration, the specimens were crushed, and water diffusion depth was measured.
- Attack acid: after a 28-day water cure (zero time), the $(40 \times 40 \times 160)$ mm³ mortars specimens were weighed to determine the mass (M_0) before being subjected to immersion for 14, 28, and 90 days in acid sulfuric solution H_2SO_4 concentrated at 5%. They were used to estimate the loss in mass according to the standard ASTM C 267-96 [19]. The attack solution was renewed every 15 days.

3 Results and discussion

3.1 Compressive strength

The variation of compressive strength as a function of time is presented in Figure 3. We note that the substitution of part of the sand by rubber aggregates is accompanied by a decrease in compressive strength and that for the different ages studied. This decrease increases with the increase in the substitution rate. The drop in compressive strength is explained by the fragile adhesion between the cement matrix and the rubber aggregate, as well as the low rigidity of rubber aggregates compared to that of natural aggregates [20,21].

For example, at the age of 28 days, the compressive strength was 41.05MPa for the reference mortar (M) against compressive strengths of 21.43 MPa and 25.57 MPa for the RM25% and RMT25% mortars respectively, decreases of 47.80% and 37.71% respectively. Therefore, for RMT25%, there is an improvement in compressive strength of 19.3% compared to RM25%. The same for RMT10% and RMT17.5% mortars, there is an improvement in compressive strength but with different speeds. Improvement of 15.02% for the RMT10% and of 20.46% for the RMT17.5% compared to RM10% and RM17.5% respectively.

The treatment of rubber aggregates with the NaOH solution contributed to an increase in the compressive strength of the mortars studied (improvement of more than 15%). This increase is justified by the fact that the treated rubber aggregates have undergone considerable modifications in the roughness of their outer surfaces, which has improved their adhesion to the cement matrix. In addition, the treatment of rubber aggregates with the NaOH solution improved hydrophilicity and homogeneity of these particles, thus increasing the rate of water

transfer around the particles, which can also ensure the compilation of hydration of cement around particles [11]. Similar results have been observed by Naji Hilal [22].

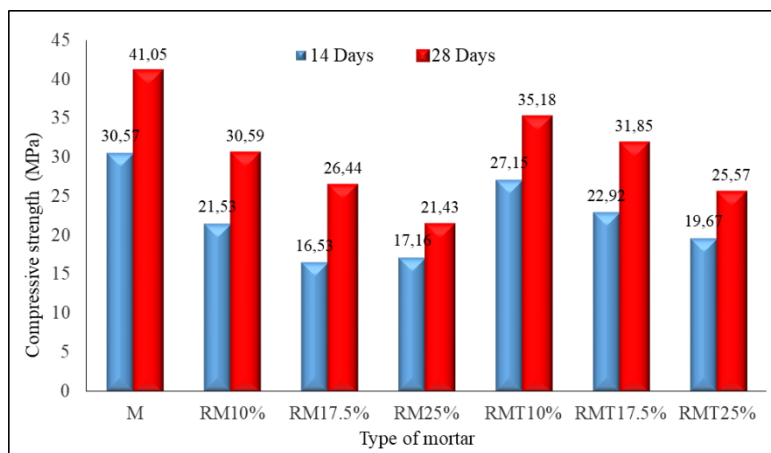


Figure 3: Compressive strength of the mixtures as a function of curing time

3.2 Flexural Tensile Strength

The results of the flexural tensile strength at the age of 14 and 28 days are shown in Figure 4. For the flexural tensile strength, the observation is the same as for the compressive strength, a decrease in the flexural tensile strength of rubber mortars compared to the reference mortar. This drop increase with increasing dosage of rubber. The treatment of rubber aggregates with NaOH solution improved the flexural tensile strength of rubber mortars. For example, at the age of 28 days, the RM25% mortar gave a flexural tensile strength of 4.4 MPa, therefore, a decrease of 46.24% compared to the reference mortar (8.18 MPa); against a flexural tensile strength of 5.76 MPa for MCT25%, so a decrease of 29.69% compared to the reference mortar (M). Therefore, NaOH treatment of rubber aggregate showed an improvement of 30.78% compared to MC25%.

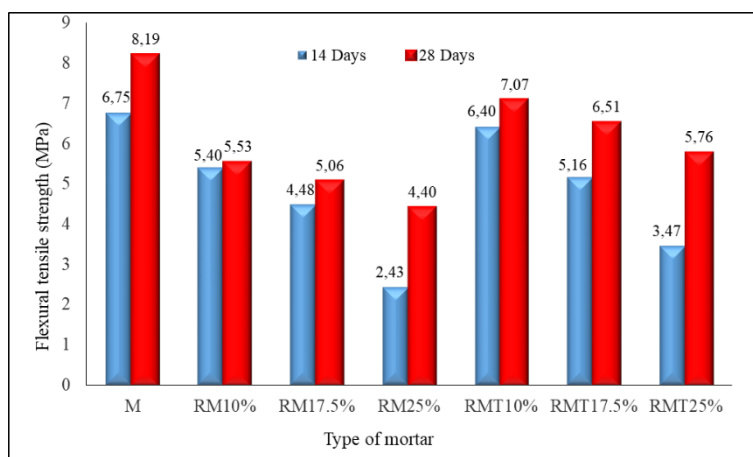


Figure 4: Flexural tensile strength of the mixtures as a function of curing time.

3.3 Absorption by capillarity

From Figure 5, we notice that the rubber aggregates decrease the amount of water absorbed gradually as the rate of rubber aggregates increases. After 48 hours, the quantity of water absorbed by the mortars RM10%, RM17.5%, RM25%, RMT10%, RMT17.5%, RMT25% was respectively reduced by 3.48% ; 7.68% ; 22.78% ; 5.39% ; 17.25% and 30.43% compared to that of the reference mortar (M). The incorporation of rubber aggregates in the cement matrix tends to limit the water absorption of the composite. The addition of rubber particles decreases the amount of water absorbed, because the rubber particles are hydrophobic, do not absorb the water [23]. Similar results have been found by [23,24].

We also note that the quantities of water absorbed by mortars with treated rubber are lower than the quantities of water absorbed by mortars with untreated rubber. This decrease varies between 1.98% and 10.36%. The decrease in water absorption is justified by the improvement in the adhesion between the cement paste and the rubber aggregates. Similar results have been found by [25].

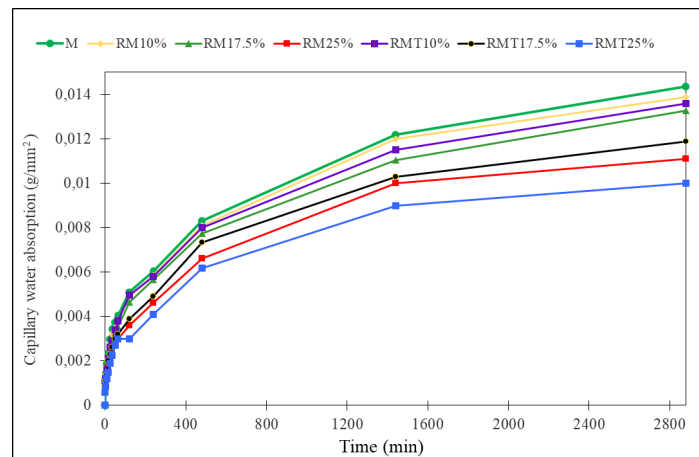


Figure 5: Absorption by capillarity of different types of mortars mixtures

3.4 Water absorption by total immersion

From Figure 6, it may be noted that the water absorption by total immersion of untreated rubber mortars is greater than that of reference mortar, and it increases with the increase in the substitution rate. Compared to reference mortar (M), there is an increase of 12.22% for RM10% against an increase of 24.44% for mortar RM25%. This result could be linked to the pores generated by the rubber aggregates due to their non-polar nature and their tendency to trap air on the surface. Air trapped in the mortar containing rubber aggregates makes the mortar more porous, thus becoming more permeable and thus allowing increased water [26].

For mortars with treated rubber, there was a remarkable reduction in the amount of water absorbed by total immersion of these mortars compared to mortars with untreated rubber aggregates and compared to reference mortar (M). It goes from 7.20% for (M) to 7.03% for RMT10%, 6.19% for RMT17.5% and 4.96% for RMT25%. So a decrease of 2.36%, 14.03%,

and 31.11% respectively compared to (M). This reduction in water absorption is justified by the improvement in the adhesion between the cement paste and the rubber aggregates which has made it possible to reduce the voids through which water can infiltrate. This same trend was observed by [27].

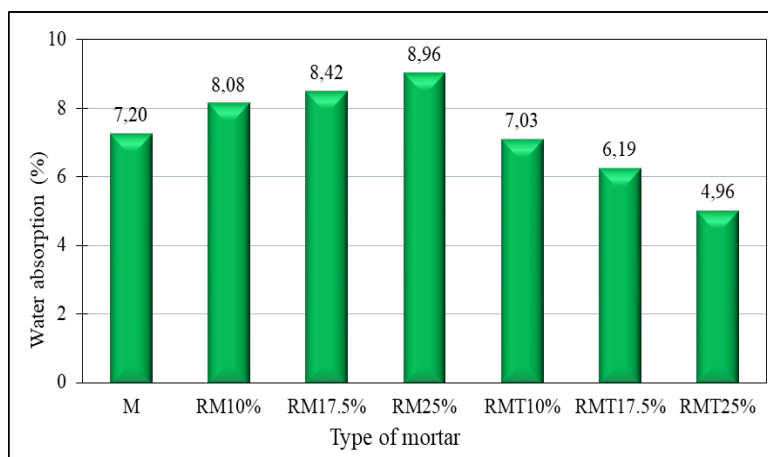


Figure 6: Water absorption of different types of mortars mixtures

3.5 Water-accessible porosity

In Figure 7, we have assembled the results of the measurements of the Water-accessible porosity of the different study mortars. We note that the porosity of rubber mortars is slightly lower than that of reference mortar, and that it decreases with an increasing substitution rate. For example, the porosity of the reference mortar (M) is 14.77% against a porosity of 13.38% for the rubber mortar RM25%, therefore a decrease of 9.41%. This decrease can be justified by the fact that rubber is a hydrophobic material that does not absorb water.

For mortars with treated rubber granulate, there is a considerable reduction compared to reference mortar (M) as well as compared to mortars with untreated rubber granulate. Compared to reference mortar (M), there are decreases of 20.65%; 24.78%, and 36.63% for mortars (RMT10%); (RMT17.5%) and (RMT25%) respectively. This reduction in porosity is always justified by the treatment of the rubber aggregates with the NaOH solution which has improved the adhesion between the cement paste and the rubber aggregates and has reduced the voids through which water can infiltrate.

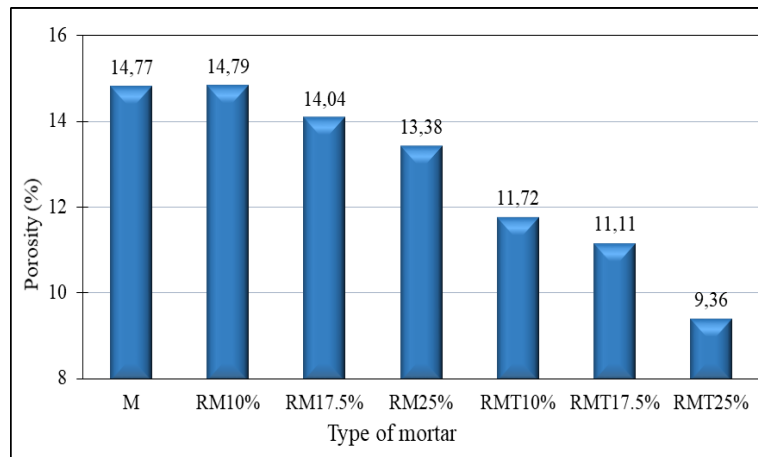


Figure 7: Porosity of different types of mortars mixtures

3.6 Water permeability depth

From Figure 8, we notice that the depth of water penetration of mortars containing rubber aggregates is greater than that of reference mortar, and that it increases with the increase in the substitution rate. It goes from 2.1cm for reference mortar to 3.4cm; 4.2cm; 5.7cm; 2.9cm; 3.1cm and 4.8cm for rubber mortars RM10%; RM17.5%; RM25%; RMT10%; RMT17.5% and RMT25% respectively. Expressed as a percentage, 36%; 68%; 128%; 16%; 24% and 92% respectively.

Moreover, we note that the water penetration depths for mortars with treated rubber are lower than the water penetration depths for mortars with untreated rubber. This decrease is the order of 55.56%; 64.71% and 28.13% for RMT10%; RMT17.5% and RMT25% respectively. The decrease in permeability is always justified by the fact that the treatment with the NaOH solution improved the adhesion between the cement paste and the rubber aggregates which made it possible to reduce the voids through which water can infiltrate.

Although the porosity and water absorption of mortars with treated rubber aggregates is lower than that of reference mortar (M), the permeability increases. The reason for this behavior is the lack of good bonding between the rubber aggregates and the cement paste, where the interface surface between the cement paste and the rubber aggregates acts as the bedding for pressurized water to flow in the mortar containing rubber [28]. Similar results have been observed by Ganjian et al. [28].

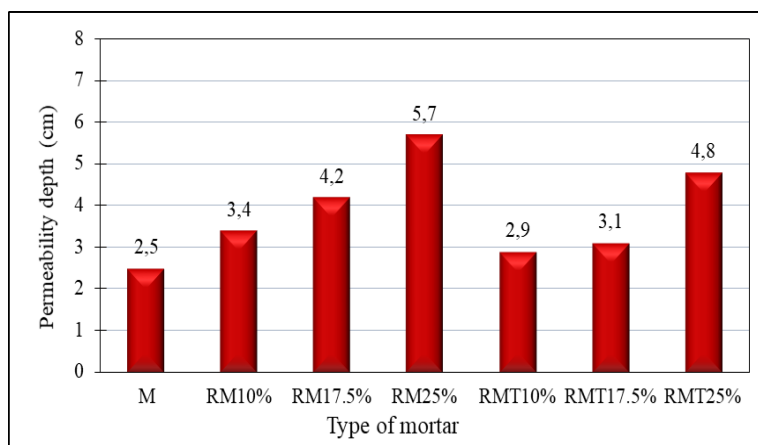


Figure 8: Water permeability depth results

3.7 Attack with sulfuric acid H_2SO_4 (loss in mass)

The values of the loss in mass test observed after 14, 28, and 90 days for the mortars studied are presented in Figure 9. The substitution of part of the sand by rubber aggregates is accompanied by a loss in mass, and that for the different ages studied. This loss in mass decreases with the increase in the substitution rate of sand by rubber aggregates. This same tendency has been observed by Kechkar et al. [29]. For example, at the age of 90 days, we notice a loss in mass of 22.98% for reference mortar (M) against losses in mass of 20.18% ; 17.93% ; 12.76% ; 15.43% ; 13.12% and 9,38% for rubber mortars RM10% ; RM17,5% ; RM25% ; RMT10% ; RMT17,5% and RMT25% respectively. This reduction of loss in mass for mortars containing rubber aggregates is justified by the nature of being chemically resistant to the penetration of acid of these particles.

We also note that the mortars with treated rubber showed a lower loss in mass than that of the mortars with untreated rubber. Mortars with treated rubber granulate showed a decrease in mass loss of 23.54%; 26.83% and 26.49% compared to RM10%; RM17.5% and RM25% respectively. This reduction in mass loss is justified by the improvement in the adhesion between the cement paste and the rubber aggregates, which has made it possible to reduce the voids through which the acid can infiltrate.

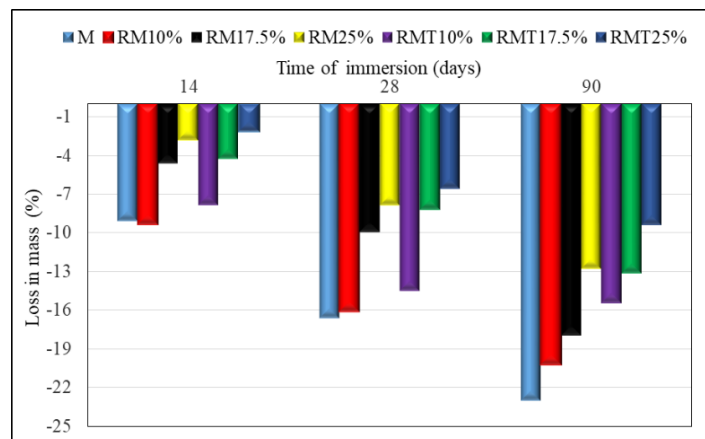


Figure 9: Variation of the mass of mortar according to the immersion time in H_2SO_4

4 Conclusions

This experimental study was carried out to evaluate the influence of the treatment of rubber aggregates with the solution (NaOH) on the durability of mortars based on rubber aggregates as a partial replacement for ordinary sand. Rubber aggregate partially replaced sand at 0%, 10%, 17.5%, and 25% by volume. From the results, we can draw the following main conclusions:

- Generally, the incorporation of rubber aggregates to mortars reduces the mechanical characteristics of the mortars. However, the treatment of rubber aggregates with NaOH can decrease this negative point or at least reduce their effects to acceptable limits.
- The use of rubber aggregates lowers the amount of absorption by capillarity and porosity. This decrease is more significant in the case of rubber aggregates treated with the solution (NaOH) compared to untreated rubber aggregates.
- The water absorption by total immersion of mortars containing rubber aggregates is greater than that of reference mortar. However, the treatment of these aggregates with the NaOH solution improved this property. Mortars with treated rubber aggregates gave a lower water absorption than ordinary mortar.
- The water permeability of mortars containing rubber aggregates is higher than the reference mortar. The rubber granulate treatment with NaOH solution has improved this property, mortars with treated rubber aggregates have lower water permeability than mortars with untreated rubber aggregates.
- Treatment of rubber aggregates with NaOH improved resistance to chemical attack by H_2SO_4 . A reduction in the mass loss of mortars with treated rubber aggregates compared to reference mortar and mortars with untreated rubber aggregates.

Therefore, the treatment of rubber aggregates with the NaOH solution has improved the mechanical performance and durability of rubberized mortars by improving the adhesion between the rubber aggregates and the cement matrix.

References

- [1] Sukontasukkul P & Tiamlom K (2012). Expansion under water and drying shrinkage of rubberized concrete mixed with crumb rubber with different sizes. *Construction and Building Materials*. 29, 520–526. DOI:10.1016/j.conbuildmat.2011.07.032.
- [2] Qiao D, Baoshan H & Xiang S (2013). Rubber modified concrete improved by chemically active coating and silane coupling agent. *Construction and Building Materials*. 48, 116–123. <https://doi.org/10.1016/j.conbuildmat.2013.06.072>
- [3] Roychand R, Gravina RJ, Zhuge Y, Ma X, Youssf O & Mills JE (2020). A comprehensive review on the mechanical properties of waste tire rubber concrete. *Construction and Building Materials*. 237,117651. <https://doi.org/10.1016/j.conbuildmat.2019.117651>
- [4] Reda Taha MM, El-Dieb A, Abd El-Wahab M & Abdel-Hameed M (2018). Mechanical, fracture, and microstructural investigations of rubber concrete. *Journal of Materials in Civil Engineering*. 20 (10), 640–649. DOI: 10.1061/(ASCE)0899-1561(2008)20:10(640).
- [5] Svoboda J, Dvorský T, Václavík V, Charvát J, Mácalová K, Heviánková S & Janurová E (2021). Sound-Absorbing and Thermal-Insulating Properties of Cement Composite Based on Recycled Rubber from Waste Tires. *Construction and Building Materials*. 23(2),1084-1092. DOI: 10.1016/j.conbuildmat.2008.05.021
- [6] Bhaskar M A, Ravichandran P T, Annadurai R & Kannan Rajkumar P R (2018). Studies on Properties of Concrete Using Crumb Rubber as Fine Aggregate. *International Conference on Intelligent Computing and Applications*. Advances in Intelligent Systems and Computing 846, Proceedings of ICICA. Springer Nature Singapore. https://doi.org/10.1007/978-981-13-2182-5_2
- [7] Ben Nakhai A & Alhumoud JM (2020). Properties of Concrete Containing Scrap (Recycled) Tire-Rubber. *Journal of Engineering and Applied Sciences*. 15 (2), 653-658. DOI: 10.36478/jeasci.2020.653.658
- [8] Marques AC, Akasaki JL, Trigo APM & Marques ML (2008). Influence of the surface treatment of tire rubber residues added in mortars. *IBRACON Structures and Materials Journal*. 1, 113-120. DOI: 10.1590/S1983-41952008000200001
- [9] Mohammadi I, Khabbaz H & Vessalas K (2015). Enhancing mechanical performance of rubberised concrete pavements with sodium hydroxide treatment. *Materials and Structures*. DOI: 10.1617/s11527-015-0540-7
- [10] Qingwen M & Jinchao Y (2013). Effect on Mechanical Properties of Rubberized Concrete due to Pretreatment of Waste Tire Rubber with NaOH. *Applied Mechanics and Materials*. 897-904. DOI: 10.4028/www.scientific.net/AMM.357-360.897
- [11] Ruizhe S, Jiaqing W, Shuaicheng G, Qingli D & Song H (2018). Evaluation of laboratory performance of self-consolidating concrete. *Journal of Cleaner Production*. 180, 823-831. <https://doi.org/10.1016/j.jclepro.2018.01.180>
- [12] NA 442. (2000). Algerian standard. Hydraulic binders, current cements: composition, specification and conformity criteria. 2nd edition. IANOR. Algeria
- [13] NF EN 196-1 (2006). Methods of testing cement – Part 1: Determination of strength
- [14] Al-Khuzai MG, Al-Humeidawi, BH & Abbas Al-Sa'idi RF (2020). Assessment of the mechanical properties of concrete pavement containing crumb rubber of tires. *IOP Conference Series Materials Science and Engineering* 737:012141. DOI: 10.1088/1757-899X/737/1/012141.
- [15] EN 480-5. (2006). Admixtures for concrete, mortar and grout - Test methods - Part 5: determination of capillary absorption.
- [16] NBN B15215. (2018). Testing hardened concrete - Absorption of water by immersion.
- [17] EN 18-459. (2010). Concrete - Testing hardened concrete - Testing porosity and density
- [18] NF EN 12390-8. (2019). Testing hardened concrete - Part 8 : depth of penetration of water under pressure
- [19] ASTM C 267-96 (1996). Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacing and Polymer Concretes.
- [20] Lia G, Stubblefield MA, Garrick, G, Eggers J, Abadie C & Huang B (2004). Development of waste tire modified concrete. *Cement and Concrete Research*. 34, (12), 2283-2289. <https://doi.org/10.1016/j.cemconres.2004.04.013>

- [21] Najim KB & Hall MR (2010). A review of the fresh/hardened properties and applications for plain-(PRC) and self-compacting rubberized concrete (SCRC). *Construction and Building Materials*. 24, 2043–2051. DOI:10.1016/j.conbuildmat.2010.04.056.
- [22] Naji Hilal N (2017). Hardened properties of self-compacting concrete with different crumb rubber size and content. *International Journal of Sustainable Built Environment*. 6, 191-206. <https://doi.org/10.1016/j.ijbsbe.2017.03.001>
- [23] Boukour, S & Benmalek, ML (2016). Performance evaluation of a resinous cement mortar modified with crushed clay brick and tire rubber aggregate. *Construction and Building Materials*. 120, 473–481. <https://doi.org/10.1016/j.conbuildmat.2016.05.119>.
- [24] Benazzouk A, Douzane O, Langlet T, Mezreb K, Roucoult JM & Quéneudec M. (2007). Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes. *Cement and Concrete Composite*. 29, 732–740. DOI:10.1016/j.cemconcomp.2007.07.001.
- [25] Segre N & Joekes I (2000). Use of tire rubber particles as addition to cement paste, *Cement and Concrete Research*. 30, 1421–1425. DOI: 10.1016/S0008-8846(00)00373-2.
- [26] Adamu M & Uche OAU (2014). Durability properties of concrete containing scrap tyre as fine and coarse aggregate in Concrete. *International Journal of Scientific and Engineering Research*. 5(11), 628-634. DOI
- [27] Ruizhe S, Shuaicheng G & Qingli D (2017). Durability performance of rubberized mortar and concrete with NaOH-Solution treated rubber particles. *Construction and Building Materials*. 153, 496–505. <http://dx.doi.org/10.1016/j.conbuildmat.2017.07.085>
- [28] Ganjian E, Khorami M & Maghsoudi AA (2009). Scrap-tyre-rubber replacement for aggregate and filler in concrete. *Construction and Building Materials*. 23, 1828-1836. <https://doi.org/10.1016/j.conbuildmat.2008.09.020>
- [29] Kechkar C, Belachia M & Cherait Y (2020). Contribution to the study of the durability of rubberized concrete in aggressive environments. *Civil and Environmental Engineering Reports*. 28 (2), 111-129. DOI: 10.2478/ceer-2020-0009.