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Original Research Article

CONTRIBUTION TO THE STUDY OF THE DURABILITY OF RUBBERIZED CONCRETE IN AGGRESSIVE ENVIRONMENTS

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Abstract

Today, much of the world's waste, in particular used tires, is accumulating as a potential source of major environmental and economic problems. In order to better preserve the environment, and in the face of changes in the legislation in force, many recovery actions have been carried out especially in the field of building materials.

The present research aims to contribute to the study of the mechanical properties and durability of concretes based on rubber aggregates. To achieve this objective, we have contemplated incorporating therein amounts of rubber granules according to different volume substitution percentages being 10%, 17.5%, and 25%. A comparison of the results with a control concrete has been established.

The obtained results make it possible to demonstrate that the substitution of a percentage of sand by rubber granules decreases the mechanical strengths and increases the expansion in water. On the other hand, it improves the resistance to attack from H_2SO_4, Na_2SO_4, and seawater. The latter is evaluated by the loss and gain in mass as well as the loss in mechanical resistance, especially in the long term (more than 90 days), decreases drying shrinkage, thus decreasing microscopic cracks and providing better durability.

Key words: concrete, tire, durability, rubber, waste, aggressive environments

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1. INTRODUCTION

In recent years in Algeria, the demand for aggregates has progressively increased to meet the needs of major projects being implemented. With the prohibition on the extraction of alluvial materials, the depletion of certain natural deposits of aggregates, and the difficulties in setting up new quarry operations, the search for new sources for the supply of aggregates is imposed [6].
The use of waste and other by-products in the building sector simultaneously responds to the need to save natural resources in aggregates as well as the obligation to limit the disposal of ultimate waste. Among these wastes, there is a distinction between rubber waste, which represents an important recoverable waste in both volume and mass, estimated at 45.65 thousand tons per year in ALGERIA [11, 26].
Today, these wastes are accumulating and are a potential source of major environmental and economic problems. In order to better preserve the environment, and in the face of changes in the legislation in force, several valorization actions have been carried out, particularly in the domain of building materials [11].
Various research has been done to study the properties of concrete incorporating rubber aggregates. The researchers found that a mixture of concrete containing granular rubber can improve toughness [4], reduces the unit weight [22], improves ductility and resistance to thermal changes [16], improve sound absorption [23], and provides better durability when compared to ordinary concrete [3,5,20]. However, there are few studies on the behavior of cement-based materials containing rubber granules exposed to aggressive environments.
The present research aims to understand the influence of the incorporation of rubber granulate on the mechanical properties as well as the durability properties of concrete in which a certain percentage of natural sand has been substituted by this waste. The substitution rates used are 0% (OC), 10% (RC10%), 17.5% (RC17.5%) and 25% (RC25%) of the volume of natural sand used. The concretes studied were characterized by their mechanical resistance to compression, flexural tensile, resistance to chemical attack, and expansion and shrinkage.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1. Materials

For the creation of the concrete mixtures, a CPJ-CEM II/42.5A Portland cement was used, originating from the HADJAR ESSOUD factory located in Skikda (Algeria), manufactured according to the Algerian standard NA 442-2008, and with the chemical composition as presented in Table 1. A class 0/3 of natural sand from the Tebessa region and two class 3/8 and 8/15 limestone crushed gravels from the EL-Fedjoudj and Heliopolis quarries, respectively were used.

The rubber granulate comes from the mechanical grinding of used tires, the maximum dimension of which is 2mm (Figure 1).
The physical and mechanical properties of the materials used are presented in Table 2.

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

Compounds	*CaO*	*SiO_2*	*Al_2O_3*	*FeO_3*	*MgO*	*K_2O*	*Na_2O*	*SO_3*	*PAF*	*MnO*
(%)	58.6	24.92	6.58	3.65	1.21	0.85	0.08	2.17	1.7	--

Table 2. Physical and mechanical characteristics of the materials used

	Cement	*Sand*	*G3/8*	*G8/15*	*Rubber*
Absolute density (g/cm^3)	3.11	2.56	2.6	2.6	0.87
Apparent density (g/cm^3)	1.09	1.6	1.39	1.41	0.47
Specific surface (cm²/g)	3371	--	--	--	--
Fineness modulus	--	2.26	--	--	--
Water absorption (%)	--		1.27	1.27	
Los Angeles Coefficient (%)	--	--	34	27	--

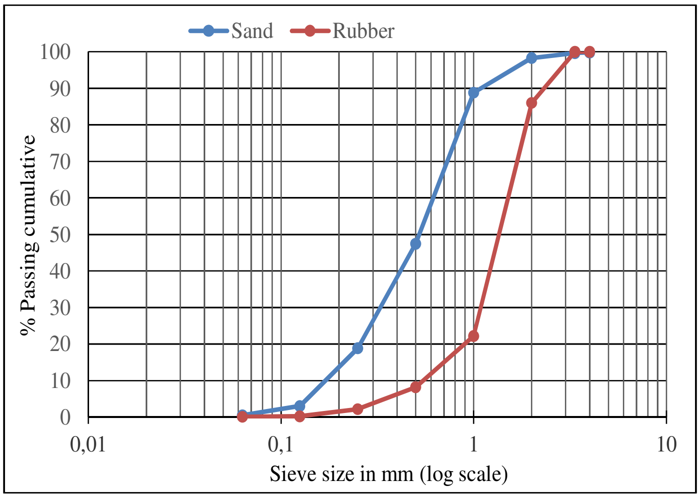


Fig.1. Sieve analysis for sand and rubber used

2.2. Experimental program

2.2.1. Mix design

For our experimental approach, we prepared four types of concrete containing substitution percentages varying from 0 to 25% of rubber granules, with a W/ C ratio of 0.6, fixed for the four formulations.

The different compositions of the concretes are grouped together in Table 3.

Table 3. Concrete mix constituents

	Cement (kg/m3)	*Water (kg/m3)*	*Gravel 8/15 (kg/m3)*	*Gravel 3/8 (kg/m3)*	*Sand (kg/m3)*	*Rubber (kg/m3)*
OC	400.00	242.00	834.00	337.00	591.00	--
RC10%	400.00	242.00	834.00	337.00	531.90	20.60
RC17,5%	400.00	242.00	834.00	337.00	487.60	36.00
RC25%	400.00	242.00	834.00	337.00	443.25	51.42

2.2.2. Testing methods

a) Mechanical resistance

The mechanical strength tests were performed according to NF P18-406 for the compressive strength test and NFP 18-407 for the flexural tensile strength test. The evolutions of mechanical resistance were studied at the age of 14, 28, 42, 56, 71, 120, and 210 days. Cubic molds of (100×100×100) mm in size were used for the compressive strength test and prismatic molds of dimensions (70×70×280) mm were used for testing the flexural tensile strength. After 24 hours of casting, the specimens were de-molded and kept in water until the relevant age of the test. The compressive and flexural tensile strength was obtained from an average of three tests.

b) Attack test

After a 28-day water cure (zero time), the (100×100×100) mm and (70×70×280) mm concrete specimens were weighed to determine the mass (M1) before being subjected to immersion for 14, 28, 45, 90, and 180 days in three different types of attack solutions:

A solution of sulfuric acid H_2SO_4 concentrated at 5%.

- A solution of sodium sulfate Na_2SO_4 concentrated at 5%
- Seawater from the Mediterranean Sea.

The attack solutions were renewed every 15 days. To evaluate the durability of concrete against chemical attack, three specimens were prepared for each mix proportion and tested for:

- Gain or loss in mass.
- Resistance to compression.
- Flexural tensile strength.

c) Shrinkage test

The shrinkage test was carried out in accordance with standard NF P15-433. The test was carried out on three specimens of dimensions (80×80×300) mm. The length of the specimens was measured after 24 hours which equals t = 0, then, they were stored in two different backgrounds, some in the open air and the remainder in the water.

The shrinkage was measured using a "retractometer" device equipped with a calibration rod and a precision digital comparator ± 0.001mm. Continuous follow-up was performed to evaluate dimensional changes at the ages of 0, 1, 2, 3, 4, 5, 6, 7, 14, 21, 28, 35, 42, 49, 60, and 90 days.

3. RESULTS AND DISCUSSIONS:

3.1. Mechanical resistances

The variation of compressive strength as a function of time is presented in figure 2. It is noted that the substitution of a portion of the sand by rubber granules is accompanied by a decrease in compressive strength and this decline increases with the increase in the substitution rate. At the age of 28 days, a compressive strength of 29.15 MPa was found for the reference concrete (OC) against a strength of 19.14 MPa for concrete RC25%, which is equivalent to a decrease of 34 %. At the age of 210 days, the compressive strength was 36.98 MPa for the reference concrete (OC) and 28.76 MPa for the concrete RC25%, thus, a decrease of resistance of 22%.

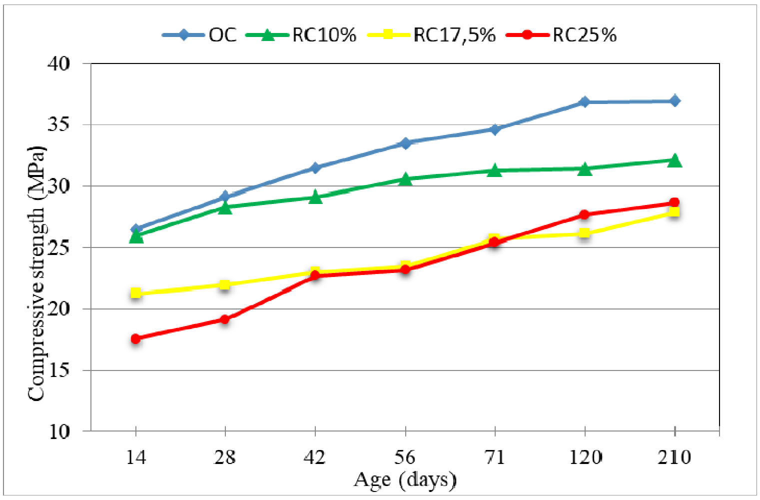


Fig. 2. Compressive strength of the mixtures as a function of curing time

For flexural tensile strength, their evolution over time is presented in figure 3. The observation is the same as for compressive strength; a decrease in the

flexural tensile strength of the rubber concretes with respect to reference concrete. This decline continues with the increase in rubber dosage.
At the age of 28 days, a resistance of 5.70 MPa was found for the reference concrete (OC) against a resistance of 3.79 MPa for the rubber concrete (RC25%), thus a decrease of 33.6%. At the age of 210 days, a flexural tensile strength of 8.34 MPa was found for the reference concrete (OC) compared to a strength of 6.40 MPa for rubber concrete (RC25%), which equates to a decrease of 23.3 %.

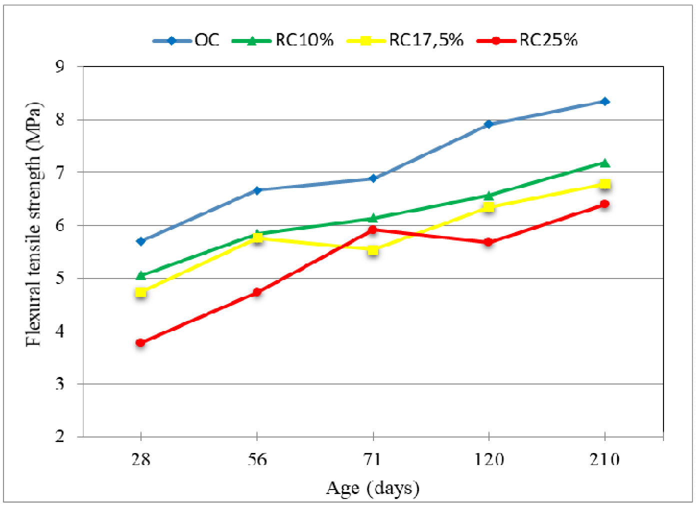
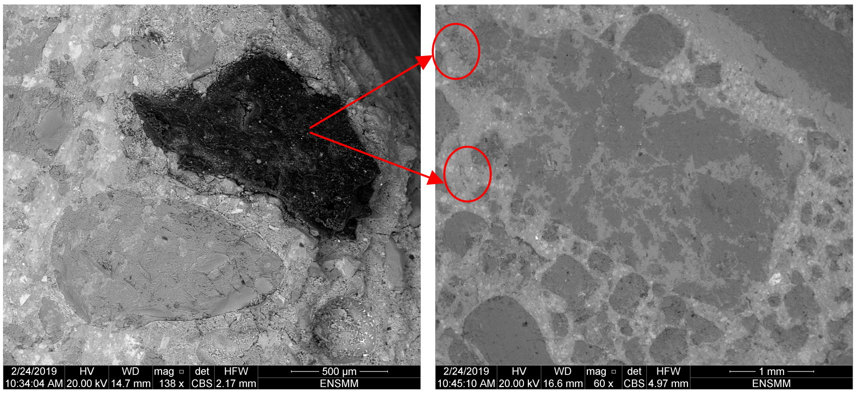


Fig. 3. Flexural tensile strength of the mixtures as a function of curing time

The results confirm previous studies on mechanical properties by Ramdani et al. [21], Hanbing et al. [15] and Gupta et al. [12]. Some authors have explained this decline in strength as being due to the low rigidity of rubber aggregates compared to that of natural aggregates [17]. Others have explained it by the fragile adhesion between the cement matrix and the rubber granulates [19]. Figure 4 (a) shows the micro-cavities present in the rubber concrete (RC25%) compared to the reference concrete, shown in Figure 4 (b).



a) RC25% **b) OC**

Fig. 4. SEM observation of the internal microstructure of the concretes OC and RC25%

The presence of these micro-cavities in the cement paste indicates feeble adhesion between the matrix and the rubber particles. This feeble inter-facial zone could play the role of micro-cracks leading to the formation of cracks at the interface of the materials, accelerating the breaking-up of the matrix of the concrete, which could explain the evolution of the decreases of compressive strengths and the flexural traction.

3.2. Attack with sulfuric acid H_2SO_4

3.2.1. Loss of mass

According to the results of the mass loss test presented in Figure 5, it is noted that after 14 days of storage in the solution, the four concretes underwent a greater weight gain in the rubberized concretes than in the ordinary concrete. This gain reflects the onset of swelling of the concretes as a result of chemical reactions occurring between the hydrates and the sulfuric acid, causing the formation of ettringite. This gain is due to the deposit of gypsum, which is formed by the reaction between portlandite and sulfuric acid. These results confirm the results found by Bisht and Ramana [7].

From 28 days of immersion, there was a significant loss of mass for the OC of 2.21% compared to the rubber concretes, which underwent a weight gain of 0.6% for RC10%, 0.79% for RC17.5 % and 1.2% for RC25%.

After 90 days of immersion in the acid, we noticed a loss of mass for the four concretes, this loss decreases with the increase of the rate of substitution of rubber. Other researchers such as Gupta et al. [13] and Thomas et al. [25] have also observed this trend.

After 180 days of immersion in the solution, there was a loss of mass of 17.37% for the OC against a mass loss of 14.45%, 11.76%, and 9.37% for rubber concrete RC10%, RC17.5%, and RC25%, respectively.

This decrease in loss of mass for concretes containing rubber particles is justified by the chemically resistant nature to the acid penetration of these particles. The hydrophobic character of the rubber particles also provides a support factor to resist the corrosive nature of sulfuric acid. On the other hand, the presence of voids and micro-cracks around the rubber particles is a delay factor in the destruction of calcium silicate hydrate (C-S-H), as ettringite first develops in the voids and cracks of the concrete matrix [14].

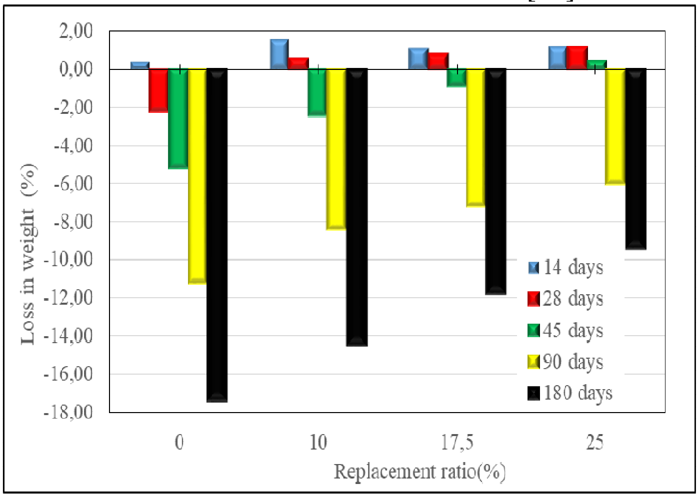


Fig. 5. Weight loss of specimens after different age of immersion in sulfuric acid

3.2.2. Compressive strength

Absolute values and percentage variations in the compressive strength of rubberized concrete mixtures after 14, 28, 45, 90, and 180 days of immersion in H_2SO_4 acid at 5% concentration are given in Figures 6 and 7.

The percentage variations in each mixture were determined by comparing the compressive strength of the samples after 14, 28, 45, 90, and 180 days of exposure to the H_2SO_4 solution with that of the samples kept in water at the same ages as previously mentioned.

As shown in Figure 6, the compressive strength of all concrete mixtures exposed to the H_2SO_4 solution decreases. However, the rate of decrease depends on the exposure time. Rubber-containing samples are also found to have the highest compressive strength from 28 days of exposure to H_2SO_4.

As expected, the maximum loss of compressive strength of all concrete mixtures was observed after 180 days of exposure to the H_2SO_4 solution. This loss accounted for more than 43.2% for all concrete mixes.

This decrease in compressive strength may be due to the depolymerization of hydration products C-A-S-H (calcium aluminate silicate hydrate) and C-S-H (calcium silicate hydrate), resulting in cracks as well as erosion of the superficial layers.

Samples containing 25% of rubber aggregates had a compressive strength loss of less than 89.9%, 70.6%, 62.8%, 46.5%, and 45.0%, respectively after 14, 28, 45, 90, and 180 days of exposure to H_2SO_4 solution compared to the control

mixture. This could be justified by the presence of rubber aggregates which delay the propagation of cracks by preventing the concrete particles from moving and thus offer better resistance to compression.
The durable nature of the rubber particles resists the corrosive nature of sulfuric acid by maintaining their structure intact, which helps to limit the propagation of cracks through the concrete matrix. In addition, the presence of rubber granulates adds some tortuosity to the concrete matrix, which limits the penetration of the acid solution. Similar results have been observed by Bisht and Ramana [7], Gupta et al. [13] and Thomas et al. [25].

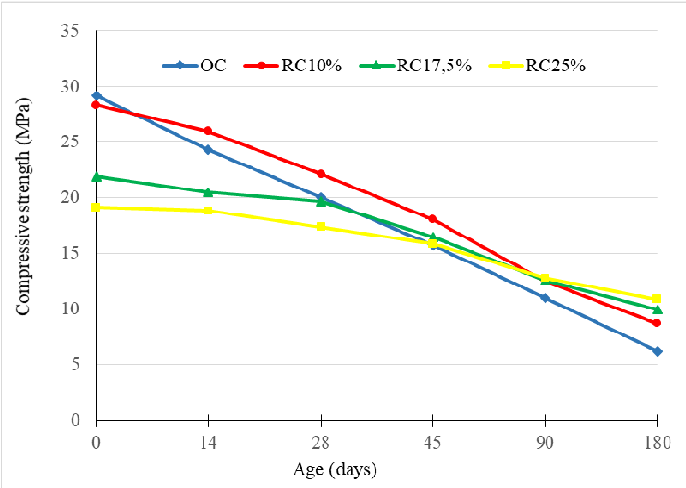


Fig. 6. Compressive strength of the mixtures in sulfuric acid

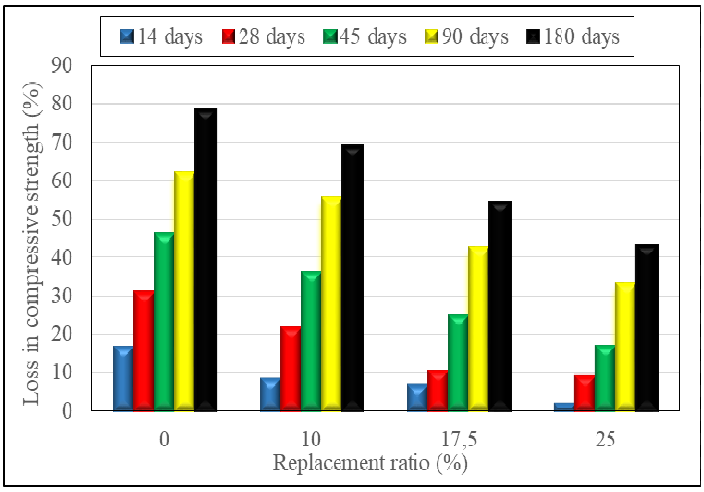


Fig. 7. Compressive strength loss of acid attacked specimens

3.3. Attack with sodium sulfate (Na_2SO_4)

3.3.1. Mass gain

From Figure 8, it is noted that the conservation of the concrete in the solution containing 5% Na_2SO_4 leads to an increase in mass. This gain in mass decreases with the increase in the rate of sand substitution by rubber. This same trend was observed by Boukour and Benmalek [10] and Medine et al. [18].
After 28 days of storage in the solution, there was a mass gain of 0.14% for the reference concrete against a mass gain of between 0.16% and 0.09% for concretes containing 10% to 25% rubber as well as a mass gain of 0.28% for the reference concrete against a gain of between 0.22% and 0.19% for rubberized concretes after 90 days of storage.
After 180 days, a mass gain of 0.82% was noted for the reference concrete against a gain of between 0.24% and 0.49% for rubberized concretes. In general, this mass gain is attributed to the absorption of the solution and the formation of gypsum and ettringite following the reaction of the sulfate with hydrated calcium aluminates to form calcium sulfo|-aluminates, and the hydroxides of free calcium in the cement to form calcium sulfate.

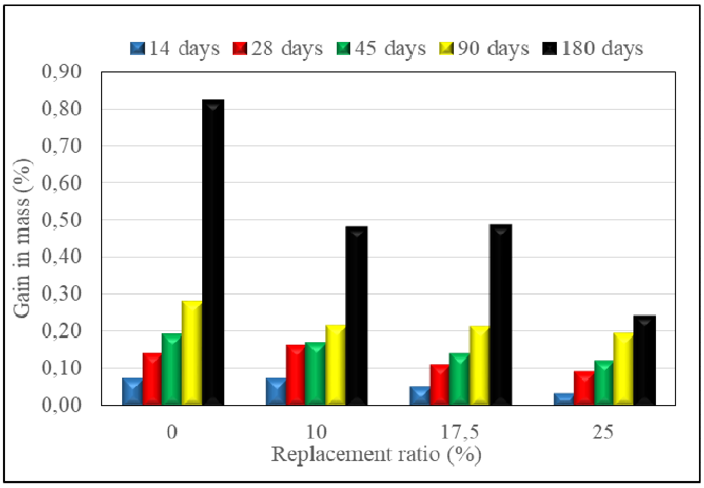


Fig. 8. Gain in mass of specimens after different ages of immersion in sodium sulfate

3.3.2. Compressive strength

Figure 9 shows the variation of the compressive strength as a function of immersion time. It is noted that until the age of 45 days, the compressive strength continues to increase, and this is the case for the four concretes. After the age of 45 days, the compressive strength begins to decrease for the reference concrete; there is a loss of 15.57% between the age of 45 and 180 days, against a continued increase for rubberized concretes. The decrease starts from the age of 90 days for the RC10% and RC17.5% concretes where the decrease is 2.96% between the ages of 90 and 180 days. For concrete RC25%, the compressive strength continues to increase. This increase in strength in rubberized concretes is justified by the elastic nature of the rubber. Indeed, it can absorb the expansion energy caused by ettringite and, in this way, avoid the failure of the structure.

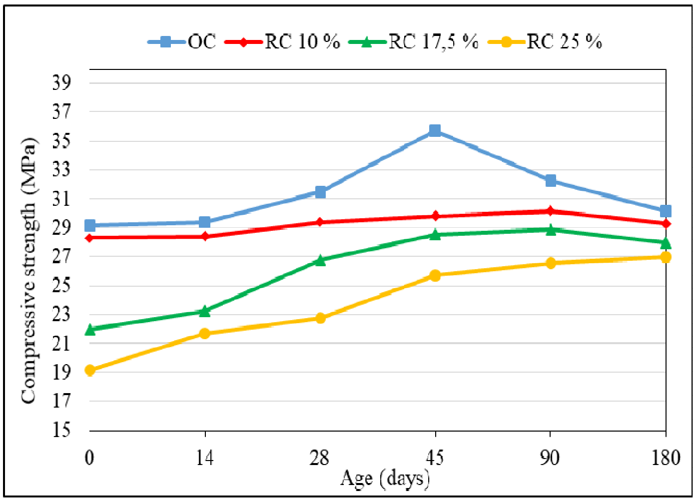


Fig. 9. Compressive strength of the mixtures in sodium sulfate

In order to better analyze the effect of sulfate attacks on the compressive strength of rubberized concrete, an anti-corrosion coefficient of compressive strength K_{fi} is proposed and expressed by equation 3.1 [27].

$$K_{fi} = \frac{f_{ci}}{f_{c0}} x100 \quad (3.1)$$

With
K_{fi} anti-corrosion coefficient of compressive strength at the age *i*,
f_{ci} compressive strength at the age i,
f_{c0} compressive strength at 28 days.

From Figure 10, it can clearly be seen that the corrosion coefficient has gradually increased with the increase of the rubber content, the maximum value recorded at the age of 180 days was 141% for concrete RC25%, 127% for concrete RC17.5%, and 103.5% for concrete RC10% against 103.4% for reference concrete. Similar results were noted in similar work by Boukour and Benmalek [10] and Xu et al. [27].

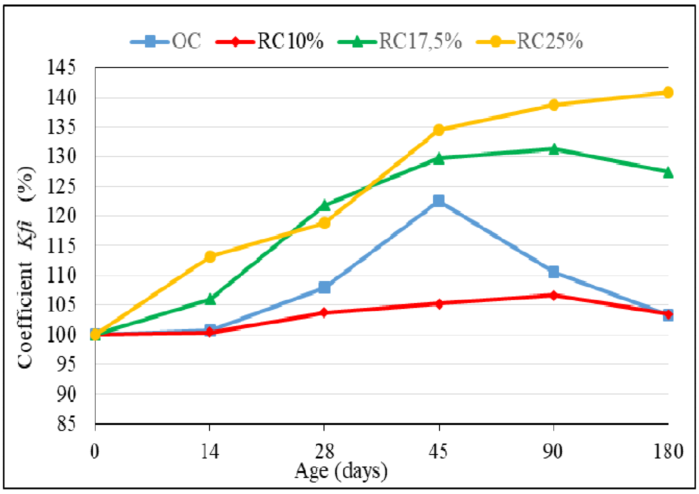


Fig. 10. Resistance to corrosion coefficient of compressive strength Kfi after immersion in sodium sulfate

3.3.3. Flexural tensile strength

Fig 11 shows the variation of the flexural tensile strength as a function of immersion time. The same observations are evident as those made for compressive strength; the flexural tensile strength continues to increase for the four types of concrete until the age of 90 days. After the age of 90 days, the reference concrete starts to lose resistance, which is equivalent to a 27% loss of strength between the age of 90 and 180 days, while the resistance continues to increase for rubberized concretes.

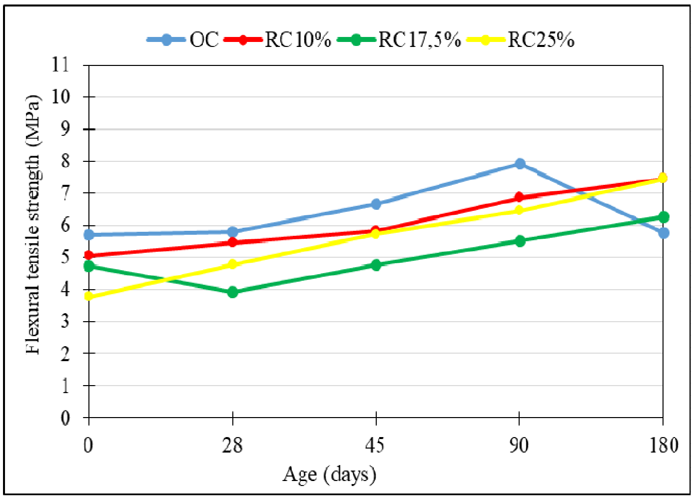


Fig. 11. Flexural tensile strength of the mixtures immersed in sodium sulfate as a function of curing time

3.4. Attack with seawater

3.4.1. Mass gain

The same was observed during storage in the Na_2SO_4 solution; the concretes immersed in the seawater gained in mass but at different speeds, increasing with the increase of the duration of immersion and decreasing with increasing rubber percentage. For example, at the age of 28 days, a mass gain of 0.44% was noted for the reference concrete against a mass gain of between 0.31% and 0.14% for rubberized concretes, while at the age of 180 days, 0.97% was noted for the reference concrete against a gain of between 0.87% and 0.69% for rubberized concrete, as shown in Figure 12. Generally, this mass gain is attributed to the absorption of water and the formation of gypsum and ettringite following the reaction between hydrates, in particular, portlandite and magnesium sulfates contained in seawater.

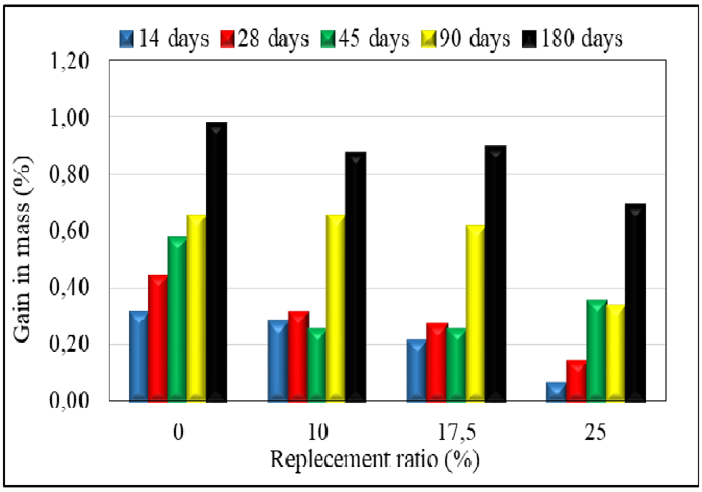


Fig. 12. Gain in mass of specimens after different ages of immersion in seawater

3.4.2. Compressive strength

Figure 13 shows the variation of compressive strength as a function of immersion time. It is noted that until the age of 45 days, the compressive strength continues to increase, and this is the case for the four concretes. After the age of 45 days, compressive strength begins to decrease for the reference concrete and concrete RC10%, there is a loss of 10.7% for the reference concrete against a loss of 7.6% for concrete RC10%, and between the ages of 45 and 180 days. Boukour and Benmalek [10] and Abdelmonem et al. [1] noted similar results in similar works.

On the other hand, for RC17.5% and RC25% rubber concretes, the compressive strength continues to increase. So, as previously stated, this increase in resistance in the rubber concrete is justified by the elasticity of rubber; it can absorb the expansion energy caused by ettringite and, in this way, avoid the failure of the structure.

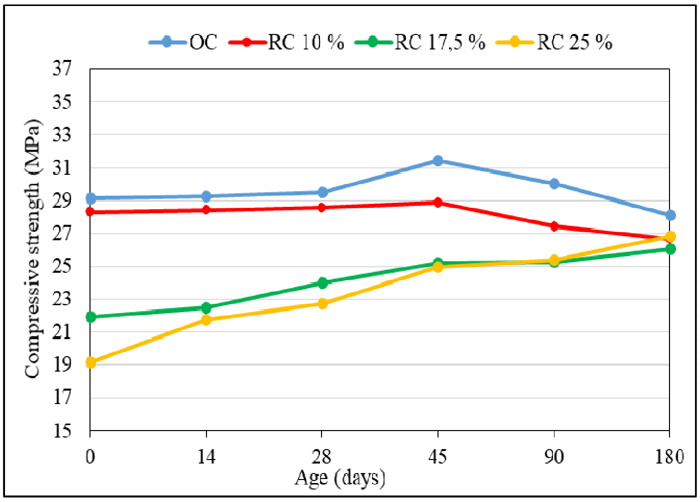


Fig. 13. Compressive strength of the mixtures in seawater

As regards the anti-corrosion coefficient K_{fi}, concerning the specimens kept in seawater, and according to Figure 14, it can clearly be seen that it increases with the increase of the rubber content. The maximum value was recorded at the age of 180 days being 140.1% for concrete RC25%, 118.6% for concrete RC17.5%, and 94.2% for concrete RC10%, against 96.4% for reference concrete. Boukour and Benmalek [10] noted similar results in similar work.

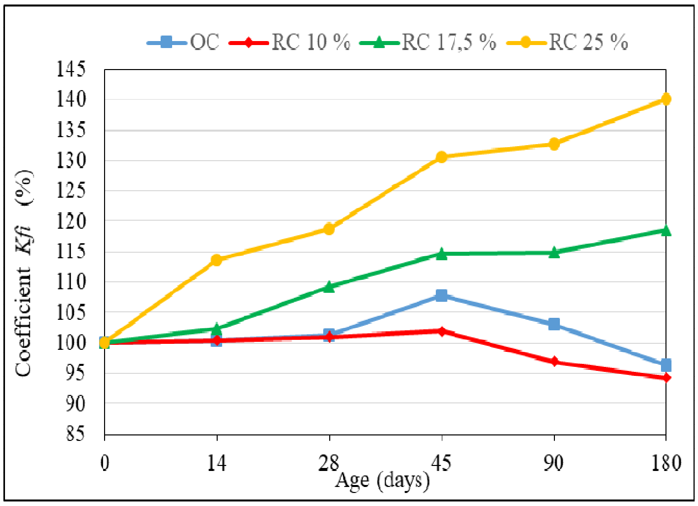


Fig. 14. Resistance to corrosion coefficient of compressive strength Kfi after immersion in seawater

3.4.3. Flexural tensile strength

The curves presented in figure 15 represent the variation of the flexural tensile strength as a function of the immersion time in seawater. The same is observed for the compressive strength; the resistance to Flexural traction continues to increase for the four types of concrete until the age of 90 days. After the age of 90 days, the reference concrete starts to lose resistance, in fact, there is a loss of 21.7% of resistance between the age of 90 and 180 days, while the resistance continues to increase for rubber concretes.

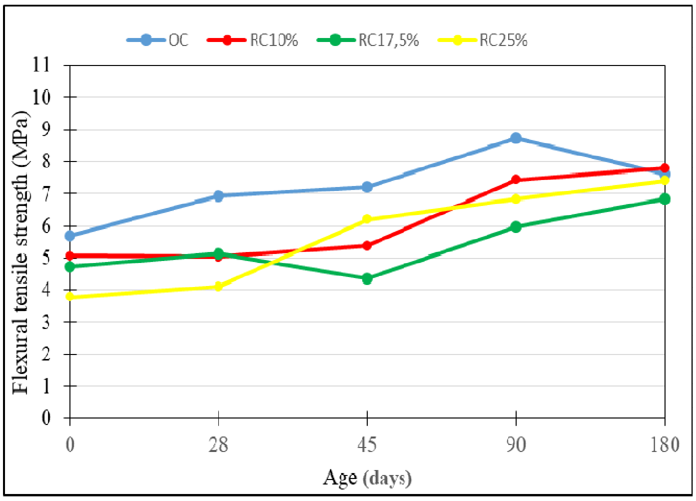


Fig. 15. Flexural tensile strength of the mixtures immersed in seawater as a function of curing time

3.5. Shrinkage

The results of the drying shrinkage are illustrated in Figure 16. Note that for the four types of concrete, shrinkage increases with increasing drying time due to the continuous loss of capillary water from the concrete.

Contrary to the results of work by Adamu et al. [2]; and Boukour and Benmalek [9], who found that the drying shrinkage of ordinary concrete is lower than that of rubberized concrete and that shrinkage increases as the substitution rate increases, it has been seen that the drying shrinkage of the reference concrete is greater than that of the rubberized concretes. The shrinkage decreases with the increase of the substitution rate up to 17.5%, beyond this, the drying shrinkage begins to increase. This decrease in shrinkage is explained by the fact that rubberized concretes absorb less water and retain the heat released during hydration of the cement [8].

Therefore, at the age of 90 days, the drying shrinkage reaches values of -0.345 mm/m (RC10%), -0.263 mm/m (RC17.5%), and -0.361 mm/m (RC25%), so a decrease of approximately 26%, 44%, and 23%, respectively, compared to that of the reference concrete (OC), which was -0.466 mm/m.

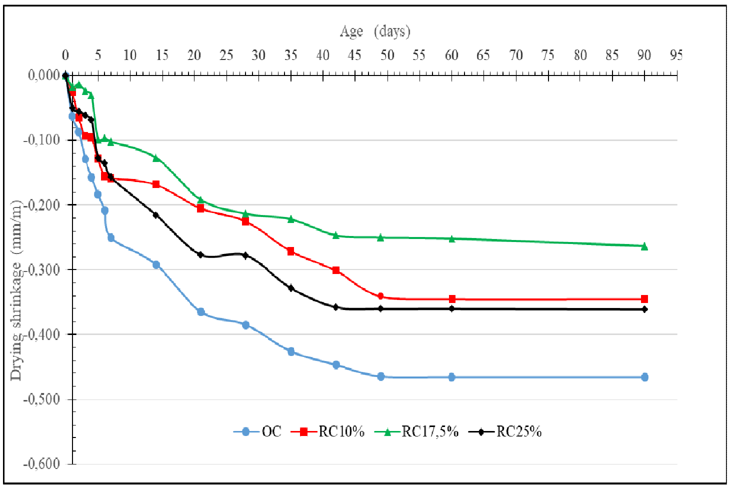


Fig. 16. Effect of the rubber tire incorporation on the drying shrinkage. Drying shrinkage of concrete mixes

3.6. Expansion

For the expansion test, the specimens are kept in water until the measurement age. The results are shown in Figure 17. It is noted that, for the four types of concrete, the expansion increases with increasing time, and we also note that the expansion of the reference concrete is lower than that of the rubberized concretes, and further that the expansion of the rubberized concrete decreases with the increase of the substitution rate. Similarly, Sukontasukkul and Tiamlom [24] studied the influence of the size of rubber granules on expansion, noting that ordinary concrete has a lower expansion than rubber concrete, and this is the case for the two sizes of studied rubber, especially for prolonged immersions (after 20 days).

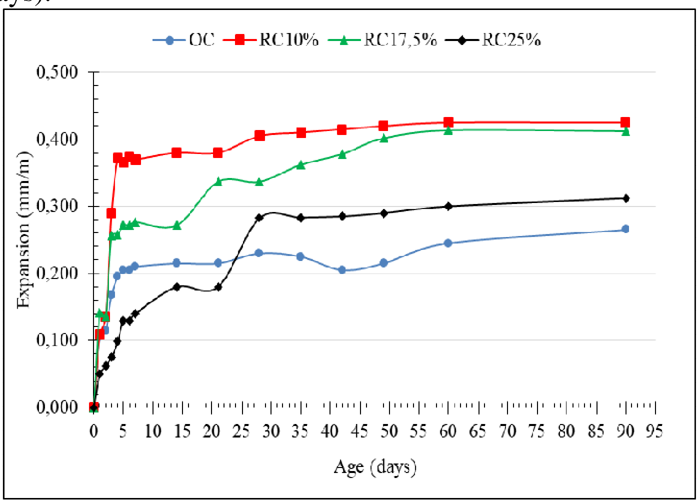


Fig. 17. Expansion of concrete mixes immersed in water

Therefore, at the age of 90 days, the expansion reaches values of 0.425 mm/m (RC10%), 0.412 mm/m (RC17.5%), and 0.312 mm/m (RC25%), an increase of approximately 60%, 55%, and 18%, respectively, compared to that of the reference concrete (OC), which was -0.265 mm/m.

4. CONCLUSION

This article presents the results of an experimental study carried out to evaluate the properties of a rubberized concrete as a partial replacement for a fine aggregate, the rubber granulate serving to partially replace the sand at 0%, 10%, 17.5%, and 25% of the volume. From the results obtained, the following conclusions can be drawn:

- The incorporation of rubber granules decreases compressive strength and flexural tensile strength. The higher the rate of substitution of rubber granules, the lower the values of the mechanical properties. A rubber granules substitution rate of 10% gave acceptable mechanical characteristics.
- The rubber content plays an important role in the resistance to chemical attacks by sulfuric acid, sodium sulfate, and seawater. It reduces the loss and gain of mass of the concrete and increases the mechanical characteristics, especially at longer durations (more than three months).
- Concrete drying shrinkage decreases with increasing percentage of rubber granules in concrete. This decrease in shrinkage can improve the durability of concrete.
- With regard to expansion, rubberized concrete has a greater expansion than ordinary concrete. Lower expansion than ordinary concrete is present at the beginning of the flooding of RC25% concrete but, after a longer period, the expansion of RC25% concrete begins to exceed that of ordinary concrete.

According to these results, we can suggest the use of rubberized concrete in the construction of foundations in very aggressive environments, and in the construction of industrial buildings, which manufacture chemical products.

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