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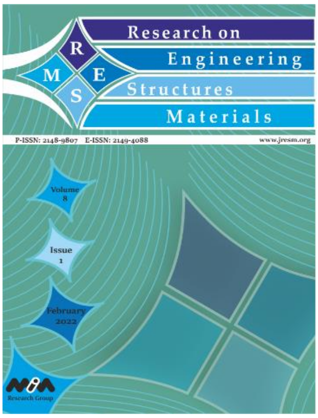

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Research Article

The freeze-thaw durability of concrete containing the rubber aggregate of tire waste

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Abstract

The influence of rubber aggregate of tire waste (RATW) under cyclic freeze-thaw attack of concrete was studied. Various concrete mixes were prepared: a plain concrete (PC) produced with natural sand and rubber concretes (CRATW) included the RATW ratios of 5, 10, and 15 % such as a partial replacement with the natural sand aggregate (NSA). After the samples exposed to the different freeze-thaw cycles (120, 240, 340), their following properties were evaluated: visual observations, mass loss, dynamic modulus of elasticity and compressive strength. Our results indicate that the inclusion of RATW increasing entrapped-air and the interfacial transition zone (ITZ) between cement matrix - rubber is weak and porous. In addition, the rubber concretes have higher resistance to freeze-thaw attack compared to plain concrete. This innovative trend could be extending the concrete structures' life in a cold climate. This clean practice of reusing RATW with cement based materials will reduce their stock in the landfills and eliminates their pollution on the environment.

1. Introduction

In a context of increasing industrial waste production, the accumulation of waste tire in the landfill presents a potential source of major environmental problems. Poor management methods of this waste such as open burning threatens nature and the environment. This dangerous practice contaminates the air, water and soil because tire waste contains toxic elements such as mineral oils and heavy metals [1,2]. This innovative solution reduces the impact of tire waste on environmental and solves the exhaustion problem of traditional aggregates, especially in poor regions in natural aggregates [3,4]. The reusing of tire waste materials with cement-based materials constitutes an alternative solution compared to the traditional mineral aggregates. Many researchers have suggested reusing RATW with cement-based materials in order to reduce their harmful effects on the environment [3,4,5].

Waste tire taken a long time to decomposed. Rubber waste materials have a higher resistance to various physical and chemical attacks [6,7]. This behavior could be reinforced the freeze-thaw resistance of concrete in a cold climate. The main damage to concrete exposed to freeze-thaw attack are the internal damage [7,8]. Many researchers had evaluated the inclusion of RATW with cement-based materials at different ratios [8,14,15]. This research revealed that RATW reduced the mechanical performance of composites incorporating rubber aggregate compared to reference concrete [14,15,16]. Other studies indicated that RATW improved the rubber- cement composite behavior, such as: water absorption by capillarity, thermal conductivity, strain capacity, ductility

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compared to control mix [17,18,9]. Recent research revealed that RATW increasing air content into fresh rubber mixes [19,23].

Concerning the rubber composites exposed to chemical attacks, Thomas and Gupta [21] revealed that rubber cement-based mixes had a high resistance to sulfate attack and carbonation than that of control. As for the freeze-thaw attack, there are less research reported that RATW improved the freeze-thaw durability of plain concrete [16,17,9]. However, we noticed that the test conditions of these studies (the maximum freezing temperature, number of cycle) were insufficient to assess the freeze-thaw resistance of rubber composite. Concerning the deicing salt attack, recent study conducted by Guelmine and Hadjab [18] reported that RATW highly increased the deicing salt-scaling resistance of rubber concrete compared to control.

Our study examined the influence of RATW on plain concrete durability exposed to a sever freeze-thaw attack. For this purpose, four cement based composites were prepared: a plain concrete and three mixes included the RATW by partial replacement with natural Sand for the rates: 5%, 10%, and 15%. The concrete durability was evaluated by their properties after the different freeze-thaw exposures.

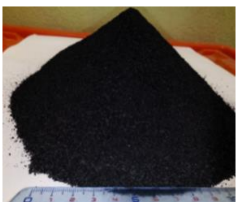
2.Materials and Methods

2.1. Materials

In this study, the Cement used for produced studied mixes was Ordinary Portland Cement CEM II/A 42.5, with a bulk density of 3020 kg/m³. The natural Sand aggregate NSA used to produce mixes have a size grading, apparent density and finesse modulus of 0.06 – 3 mm, 1500 kg/m³, 2.25 respectively. The natural crushed gravel has a maximum size of 15 mm. The RATW was produced from waste tire processing factory in Algeria. Their apparent density is 470 Kg/m³ (Fig.1). The RATW inclusion in concrete mixes (0.08 mm – 3 mm) by partial replacement with natural Sand aggregate. Fig.2 and Table 1 shows the sieve analysis and some physical properties of used aggregates, respectively.

Gravel G3/8

Gravel G8/16



RATW

NSA

Fig. 1 Used aggregates

Table 1. Some physical properties of used aggregates

Physical Properties	NSD	RATW
Specific density (kg/m^3)	2510.0	1195.0
Apparent density (kg/m^3)	1615.0	470
Water absorption (%)	1.15	0.25
Finesse modulus	2.30	3.10

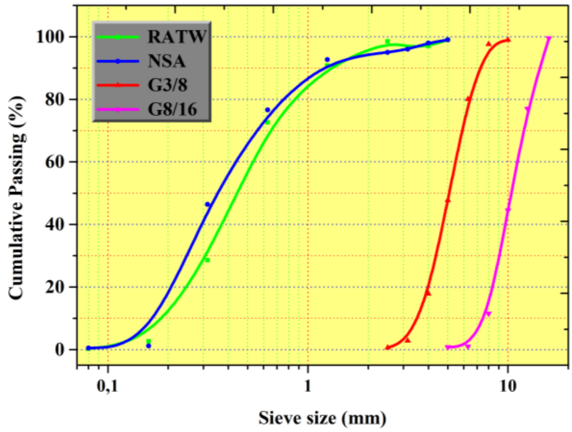


Fig. 2 Grading cures of used aggregates

2.2. Mix proportions

In this study, four mixes produced: The plain concrete PC and three rubber concretes included the RATW by partial replacement with NSA by mass, for the rates: 5%, 10%, and 15%. The mix proportions are shown in Table 2. Studied samples produced in accordance with standard NF EN 12390-2. First, the concrete samples were cast in cubical samples 100 x 100 x 100 mm^3. After 24h ± 1h. All samples were unmolded and filed in the tap water tank for 28 days (T = 21 ± 1°C, HR= 100%), then in the laboratory conditions (T = 19 ± 1°C and HR = 60 ± 3 %). The mix CRATW10% means the concrete sample included 10% of reused rubber Aggregates of tire waste.

Table 2. Mix proportions

Component (Kg/m^3)	Concrete mix (Kg/m^3)			
	PC	CRATW5%	CRATW10%	CRATW15%
NSA	610	580	550	520
Gravel 3/8	180	180	180	180
Gravel 8/16	970	970	970	970
Cement	400	400	400	400
Water	220	220	220	220
RATW	0	30	60	90

2.3. Freeze-Thaw Test

This study investigated the influence of RATW on the freeze-thaw durability of produced mixes. All samples have been exposed to successive cycles (24 hours) for the following thresholds: 120, 240 and 340 cycles. The Freeze-thaw test was realized by a similar process of ASTM C666 standard [19], on cubical samples (10 x10 x10) cm^3 aged 35 days. The freezer has a temperature range of (0 °C to - 30 °C).

The freeze-thaw experiment was preceded by a stage of saturation of the samples, in a tap water tank (20 ± 2 °C) during 8 days, because the critical saturation degree (uptake) increases the internal frost damage to concrete according to the reliable research [20,21]. The typical freeze-thaw cycle is composed of two stages (see Fig.3). The internal frost damage to concrete samples was evaluated by the following physical-mechanical proprieties: Visual observations, mass loss, residual dynamic modulus of elasticity, and compressive strength.

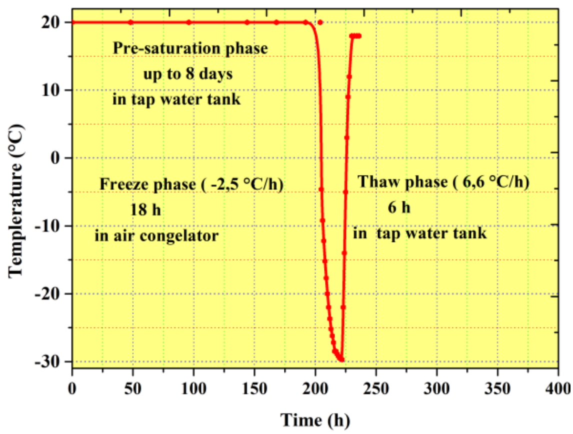


Fig. 3 Typical freeze-thaw cycle

2.5. Test Methods

This research conducted in order to investigated the influence of RATW on the freeze-thaw durability of plain concrete. The hardened properties were estimated on three samples of 10 x 10 x 10 cm^3. The fresh properties estimated were: the workability and air content. These experiments realized in accordance with Standards ASTM C143 and ASTM C231 respectively [19]. The ultrasonic velocity determined by the ultrasonic wave technique (Fig. 4), in Standard with NF P 18-418 standards [22]. The elastic dynamic modulus EDM calculated by equation (1):

$$E_{DM} = [(1 + \nu)(1 - 2\nu)/(1 - \nu)]C^2 \rho L \quad (1)$$

Where, ν, ρ, C are Poisson's ratio (0.2), bulk density (kg/m^3) and ultrasonic velocity of concrete respectively.

The durability factor was estimated for each concrete at 120 cycles, 240 cycles and 340 cycles by the following equation (2):

$$DF = \frac{E_n}{E_0} \text{x } 100\ (\%) \quad (2)$$

Where, DF: durability factor of studied samples; E_n, residual dynamic modulus of elasticity at n freeze/thaw cycles; E_0, initial dynamic modulus of elasticity at 0 freeze/thaw cycles.

Fig. 4 Ultrasonic test equipment

The SEM analysis conducted for estimated the air voids generated by RATW in the micro-structure of rubber samples which are related to concrete durability exposed to freeze-thaw. The micro-structural analysis of prepared samples was determined by scanning electron microscope SEM make at 15 kV. The experiments were realized on 2 cm 2 cut pieces from hardened samples. The best coating was carried out on the surface samples before carrying out the analysis. The compressive strength was determined on the samples (10 x 10 x 10) cm^3 according to NF EN 12390-2 Standard [23]. The freeze-thaw attack was evaluated by the following properties: mass loss, elastic dynamic modulus, and compressive strength for all prepared samples.

3. Results and Discussions

3.1. Workability

The slump test results of studied concretes are shown in Fig.5. The results indicate that RATW produced a significant reduction in the workability with the inclusion of rubber content. These reductions were about: 25%, 40% and 55% for the inclusion of 5%, 10 % and 15 % rubber sand, respectively. This trend explained by the heterogeneous shape of RATW compared to NSA. Many researchers have reported a similar trend [23,24]. According to previous studies cited above, the RATW require more water and cement, to obtain an equivalent slump than that of reference concrete [23,24]. For this reason, the RATW ratio was limited to 15%, for an easy casting of studied mixes.

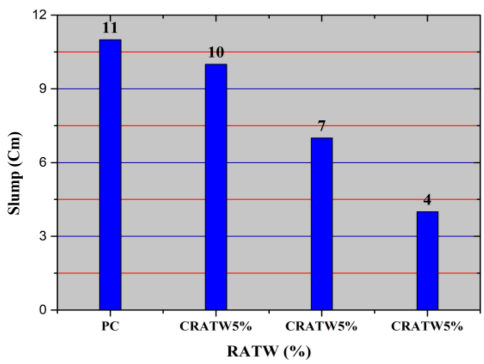


Fig. 5 Effect of RATW on the slump values of studied concretes

3.2. Entrapped – Air

Fig. 6 shows the evolution of entrapped-air values of prepared samples with RATW rate. The inclusion of RATW in concrete up to 15% produces an increase in entrapped-air rate about 5%. This behavior is due to the rigorous texture of RATW which traps air in their complex topography. Various studies [25,26] reported during the mixing of rubber mixes that RATW had a high capacity to entrap air. These results confirmed that RATW could be used as an air- entraining admixture with concrete composites.

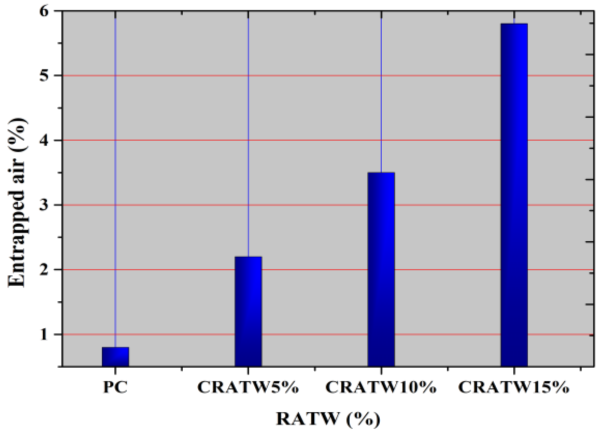
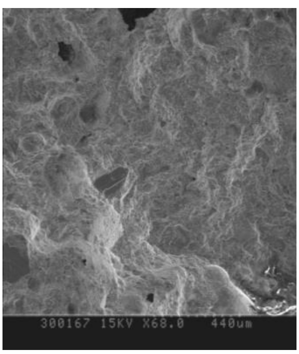


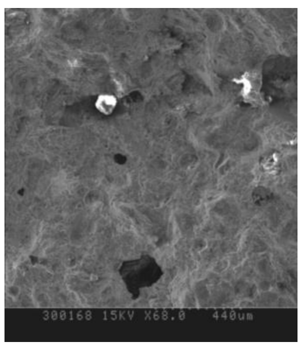
Fig. 6 Effect of RATW on the entrapped air of studied concretes

3.3. MEB Analysis

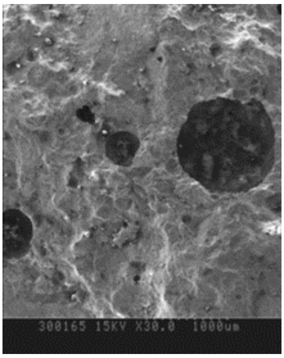
Fig. 7 appears the SEM images of rubber samples (CRATW5%, CRATW10%, CRATW15% and rubber- concrete paste ITZ). The results reveal that entrapped air (air-voids) increasing with increasing RATW content, and they are located close to rubber aggregates. This behavior is due to the complex shape of rubber aggregates as shown in Fig.7d. The Fig. 7d reveals a poor contact between Concrete -RATW that is characterized by the presence of air-voids between concrete matrix and rubber aggregate. Various studies [26,28] confirmed that the ITZ between concrete matrix - rubber is weak and porous. Air voids between the rubber and the concrete matrix can act as an air-entraining admixture to protect the concrete against freeze-thaw attacks.



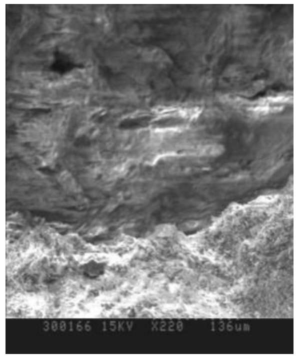
CRARW5%



CRARW10%



CRARW15%



CRARW15%

Fig. 7 Micrographs of samples obtained by SEM, ITZ represent interfacial transition zone concrete - RATW

3.3. Freeze - Thaw Durability

This section estimated the influence of RATW on the freeze-thaw durability of studied samples. The damage samples evaluated by the subsequent properties: mass loss (scaling surface) Dynamic modulus of elasticity and compressive strength, after their exposure to different freeze-thaw cycles (120 cycles, 240 cycles, and 340 cycles) (Fig. 9). The average results of properties were summarized in Table 3.

Table 3. Results of freeze-thaw test

Property	Concrete mix	Number of freeze-thaw cycles			
		0	120	240	340
Mass loss (%)	PC	0	1.82	2.90	3.50
	CRATW5%	0	0.15	0.72	1.75
	CRATW10%	0	0.07	0.60	1.08
	CRATW15%	0	0.03	0.50	1.50
Dynamic modulus of elasticity DME (MPa)	PC	35.24	31.61	25.61	18.10
	CRATW 5%	28.54	26.21	24.39	22.31
	CRATW 10%	24.80	23.60	21.92	20.35
	CRATW 15%	21.76	20.40	19.82	18.46
Compressive strength f_c (MPa)	PC	54.79	47.48	39.35	28.48
	CRATW 5%	46.84	42.48	36.90	30.87
	CRATW 10%	35.61	32.87	30.16	28.87
	CRATW 15%	30.52	29.00	27.35	26.20

3.3.1. Visual Observations

The damage properties of studied samples exposed to freeze-thaw are illustrated in Fig. 8. For 120 cycles, we noted only slight crumbling for PC samples. For 240 cycles, we observed moderate and slight scaling surface for the samples PC and CRATW5%, respectively. For 340 cycles, we observed a severe scaling surface and edges with the deterioration of paste coaling around aggregates for PC. However, we reported a moderate loss of cohesion between paste and aggregate for CRATW5%. For CRATW10%, there was slight loss crumbling with appearance of same coarse aggregate. For CRATW15%, there was only very slight scaling surface and moderate damage to edges samples caused by the presence of RATW in the edges. These results revealed that RATW improved the scaling surface of concrete exposed to freeze-thaw attack. Table 3 shown below summarizes the freeze-thaw test results.

340 cycles

240 cyclec

120 cycles

CRATW15% CRATW10% CRATW5% PC

Fig. 8 Visual appearance of concrete samples exposed to 120, 240, and 340 cycles of freeze-thaw

3.3.2. Mass Loss

Fig.9 shows the mass loss of samples (CRRP5%, CRRP10%, and CRRP15%) subjected to 120, 240, and 340 cycles of freeze-thaw. Our results reveal that RATW reduce significant the mass loss of rubber samples compared to PC (see Fig.8). These reductions were 50%, 69 %, and 57 % compared to PC samples, for 340 cycles, respectively. This behavior is justified by the nature of RATW that entraps air-voids and reduces the freeze-thaw damage to rubber samples compared to PC. This trend confirmed that the RATW could be improved the scaling surface resistance of rubber concrete, especially for CRATW10%. In the literature, there are no studies on this topic. This valuable property for RATW could be extending the concrete structures' life in a cold climate.

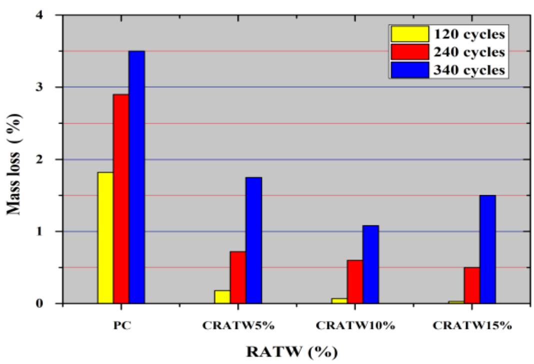


Fig. 9 Effect of RATW on the mass loss of studied samples exposed to the different freeze-thaw cycles

3.3.3. Durability Factor

Fig.10 illustrates the durability factor DF of studied samples as a function of freeze-thaw cycles. The DF reductions of samples (CRATW10% and CRATW15%) are moderate (22 % and 19%) for 340 cycles, respectively. On the other hand, the DF loss of other samples (PC and CRATW5%) are much higher (48% and 37%), respectively. Our results reveal that RATW strongly improved the freeze-thaw durability of rubber concrete. This high freeze-thaw resistance of rubber concretes is due to the entrapped-air content (0.8 to 5.8%) generated by RATW. Richardson [16] reported that entrapped-air improved the freeze-thaw durability of concrete. In addition, many researchers indicated that air-content produces by an air-content admixture in concrete between 5% to 6%, highly improved their freeze-thaw durability [29,30]. Based on this trend, the RATW could be used with concrete structures such as an entraining-air admixture.

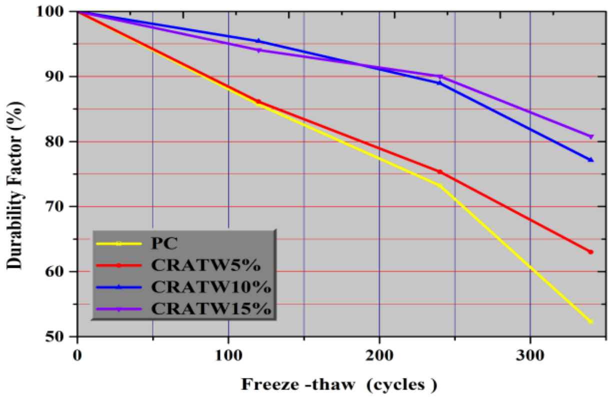


Fig. 10 Effect of RATW on the durability factor of rubber concrete subjected to different freeze-thaw cycles

3.3.4. Compressive Strength

Fig. 11 shows the residual compressive strengths of studied samples (PC, CRATW3%, CRATW10%, CRATW15%) as a function of cycle number.

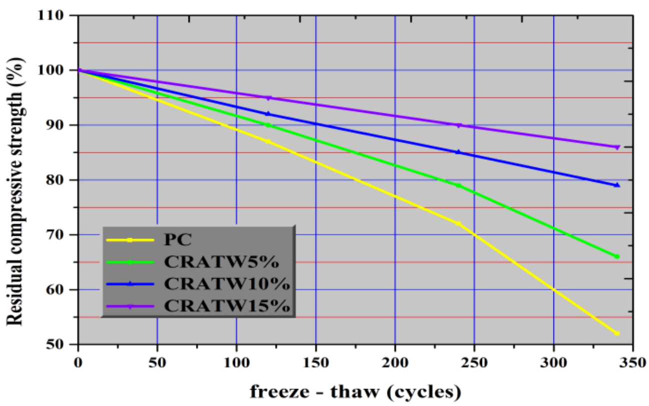


Fig. 11 Residual compressive strength of studied samples depending on the number of freeze-thaw cycles

The compressive strength drops increase with increasing number of cycles. They were moderate (48%, 34%, 21%, 14%) for samples (CRATW10%, CRATW15%) and higher for other samples, for 340 cycles, respectively. These results indicated that the rubber samples have less internal damage than the control sample. The air voids alleviate the hydraulic pressure of ice formation in the porous network of rubber samples and reduce their damage compared to PC. Richardson et al. [6,16] have shown that rubber composites exposed to 56 freeze-thaw cycles has a little loss in compression strength compared to control composite. Surely that this innovative property of RATW could be improved the concrete durability in a severe winter climate.

4. Conclusion

This research evaluated the influence of rubber aggregate of tire waste RATW on the plain concrete durability to freeze-thaw attack. The results obtained allow drawing the following conclusions:

- The Micrographs of samples obtained by SEM revealed that air-voids increasing with increasing RATW content. The interfacial transition zone ITZ between concrete matrix - rubber is weak and porous. The air-voids between rubber - concrete matrix may be behaved such as an air-entraining admixture.
- The inclusion of RATW for substitution ratio up to 15% increased the entrapped air content of rubber concrete compared to control (0.8% – 5.8%). So this study confirm that RATW could be used with concrete such as an air-entraining admixture.
- In terms of mass loss, the results revealed that the inclusion of RATW in concrete samples reduced significant the scaling surface damage to rubber concretes compared to PC. This valuable property of RATW could be extending the concrete structures' life subjected to freeze-thaw attack.
- The durability factor results showed that RATW reduced the internal frost damage to rubber concrete compared to PC. This innovative property could be improved the concrete durability in a rigorous winter climate.
- The compressive strength results indicated that concrete included RATW had high resistance to freeze-thaw attack compared to plain concrete. This behavior is due to the inclusion of rubber aggregate with concrete that increasing entrapped-air and reducing the internal frost damage to freeze-thaw attack. These results confirmed that RATW highly improved the concrete durability to freeze-thaw attack. This valuable property could be used with concrete structures installed in regions with harsh winter climates.

This study only dealt with a specific case of substitution of natural aggregates by RATW for a single type of concrete. In the next study, we will study the effect of shape and size of RATW aggregates on the behavior of high-performance concrete exposed to a severe freeze-thaw with and without de-icing salt.

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