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ELECTRICAL RESISTIVITY, PERMEABILITY AND MECHANICAL PROPERTIES OF RUBBERIZED CONCRETE

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Abstract: The application of crumb rubber from recycled tires has been used in construction as a replacement for the aggregate and fine sand in concrete. The use of these materials can improve the concrete performance and may enhance its properties along with minimizing the cost. This paper investigates the effect of 10% replacement of sand with fine crumb rubber on properties of concrete mixtures with and without silica fume. Compressive and tensile strengths, surface resistivity, and rapid chloride penetration tests were conducted. Results showed that the use of rubber without silica fume decreases the mechanical properties compared to the plain concrete, while it enhances concrete modulus. In addition, rubber had a marginal effect on the relationship between concrete mechanical properties and electric resistivity. Moreover, the rubber with silica fume had a significant effect on the electrical conductivity.

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1. INTRODUCTION

The accumulation of waste tires is considered one of the most crucial challenges for many countries. Different types of research have investigated to the use of rubber aggregates of different sizes as an additive to the cement paste/concrete mixtures. These studies were conducted to evaluate the properties of concrete incorporating partial replacement of rubber aggregates of different sizes. The studies reveal the increase in rubber aggregate contents had adverse effects on the fresh properties of concrete mixtures as; workability, slump, air content, density, unit weight (Güneyisi et al., 2004, Holmes et al., 2014). In addition, it increases the possibility of segregation in concrete mixtures (Turatsinze et al., 2008, Turatsinze, et al., 2016 and Thomas et al., 2016). These adverse effects can be attributed to the irregular shape, rough surface and nonpolar property of the rubber aggregates. Moreover, the rubber addition causes a reduction in the concrete mechanical properties as; compression and tensile strengths due to increase in air content and porosity (Issa et al., 2013, Ganesan et al., 2013, Kardos et al.2015, and Gupta et al., 2016). For instance, the compressive strength reduced at 90-days by about 31, 34, 48, 48, 67% with 10, 20, 30, 40, and 50% partial replacement of rubber aggregate (Kardos et al.2015).

This study was conducted to evaluate the effect of 10% partial replacement of sand with crumb rubber on the electrical, mechanical, and permeability properties of concrete incorporating 10% pozzolanic material as silica fume (SF).

2. Experimental procedure

2.1. Materials Properties and mixtures

Four different mixtures were prepared using general use cement (GU) as the main binder meeting the Canadian Standard Association CSA-A3001 (CSA 2008b). Silica fume (SF) of total silicon oxide content (SiO_2) 93.8% partially replaced 10% of cement content by weight.

Moreover, the coarse aggregate with nominal maximum aggregate size 9.5mm met requirements of size No.#8 ASTM C33 "Standard Specification for Concrete Aggregates". In addition, crushed sand of fineness modulus of 2.7 meeting size requirements of ASTM C33 was used as a fine aggregate. Finally, crumb rubber aggregate (CRA) (**Fig. 1),** produced by tearing the shabby scrap tires then sieved to get rubber particles met the size fraction of fine aggregate was partially replaced 10% of fine aggregate by weight. **Table (1)** shows the characteristics of coarse, fine and crumb rubber aggregates, and **Fig. (2)** Represents sieve analysis of fine aggregate and CRA. The mixtures differentiated based on the replacement porion of SF and CRA as shown in Table 2.

Figure (1) Crumb rubber

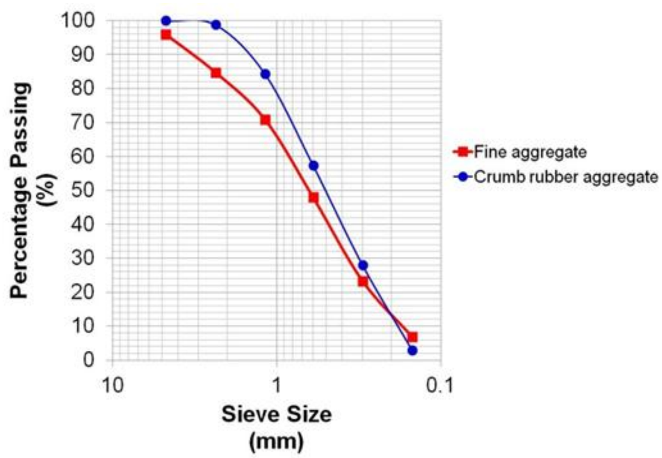

Figure (2) Sieve analysis of fine and crumb rubber aggregates

Table 1: Properties of course, fine and crumb rubber aggregates

Properties	Coarse Aggregate	Fine Aggregate	Crumb Rubber
Fineness Modulus	----	2.7% ASTM C136	----
Specific Gravity	2.7 % ASTM C127	2.615 ASTM C128	1.16 gm/cm^3 ASTM D5603
Absorption Capacity	1.30 % ASTM C127	2.73% ASTM C128	----
Loose bulk density	1360.96 kg/m^3 ASTM C29	----	0.37-0.44 gm/cm^3 ASTM D5603
Dry Rodded Density	1512.91 kg/m^3 ASTM C29	----	----

Table 2: Properties of mixtures

Mixture ID	Replacement portion (%)	
	SF	CRA
C	0.0	0.0
CR	0.0	10
S	10	0.0
SR	10	10

Constant water to cement ratio (w/c) of 0.42 was used for all mixtures. Moreover, high range water reducing admixture (HRWRA) of specific gravity 1.08g/cm^3 was used to control the slump within a range of 75mm to 110mm. General use air-entraining admixture (AEA) of specific gravity 1.01g/cm^3, and meeting the requirements of ASTM C260, and AASHTTO M154 "Standard Specification for Air-Entraining Admixtures (AEA) for Concrete" was added to the concrete mixtures to obtain the air content. Finally, viscosity modifying admixture (stabilizer) of specific gravity 1.02 g/cm^3 was added to the concretes mixtures to maintain a good distribution of CRA particles and to enhance the segregation resistance. In this study, concrete mixtures were classified into two groups: mixtures without silica fume and mixtures incorporating silica fume. Each group consisted of plain control mixture and CRA.

2.2. Specimens Preparations, Curing, and Testing

Each concrete mixture, 18 samples Ø100×200 mm, were cast to evaluate the compressive (fc), tensile strengths (ft), modulus of elasticity (E), surface resistivity (SR), and ultrasonic pulse velocity (UPV). Moreover, six samples Ø100×50 mm were prepared to evaluate rapid chloride permeability test (RCPT). The concrete mixtures of density 2327 kg/m^3 were prepared with a ratio of 1:1.45:1.25:0.40 (binder: sand: coarse aggregate: water) to obtain a target strength of 40 MPa at 28 days. Concrete was prepared, cast, and cured according to ASTM C192 “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory”. The results of all tests represented the average of three specimens. Specimens kept in the mold for 24 hrs, then de-molding and cured continuously in a lime water tank until testing.

Compressive and tensile strengths were accomplished according to ASTM C39 "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" and ASTM C496 "Standard test method for splitting tensile strength of cylindrical concrete" at ages 28 and 56 days, respectively as represented in **Fig. 3 (a,b)**. Modulus of elasticity was evaluated according to ASTM C469 "Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression" as shown in **Fig. 3 (c)**.

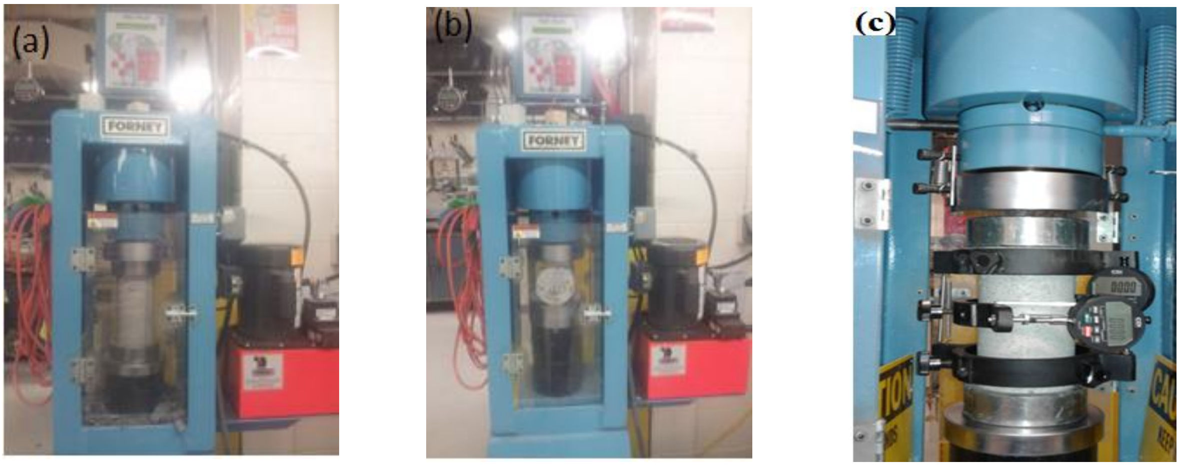

Figure (3) Tests of concrete specimens
(a) compression strength, (b) Tensile strength, (c) modules of elasticity

Surface resistivity measurements were performed every week until 56 days according to ASHTTO TP -95-11 "Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration" by a commercially available 4 point wenner probe surface resistivity meter as shown in **Fig. 4 (a)**. Ultrasonic pulse velocity (UPV) was carried out weekly until 56-days according to ASTM C597 "Standard Test Method for Pulse Velocity Through Concrete" as shown in **Fig. 4 (b)**.

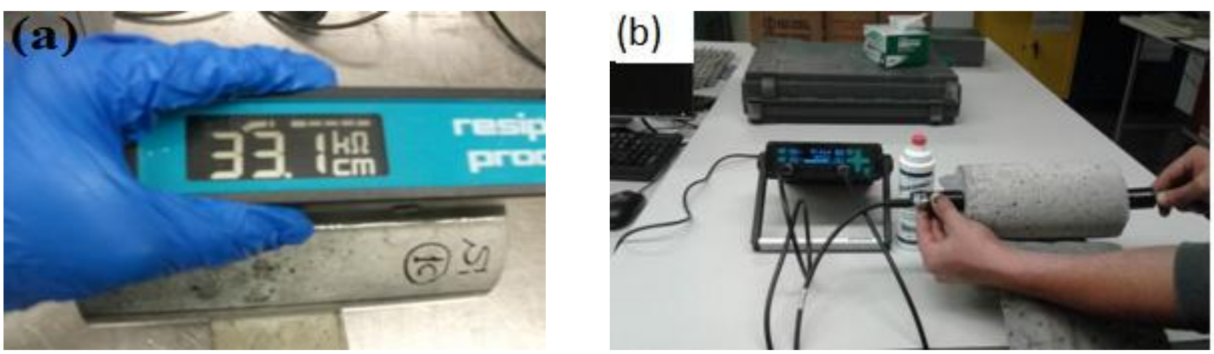

Figure (4) Tests of concrete specimens
(a) Surface resistivity, (b) Ultrasonic pulse velocity

Finally, to evaluate the penetration of chloride ions, (RCPT) was performed according to ASTM C1202 "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration" at 28, and 56-days respectively as represented in **Fig. 5 (a,b)**.

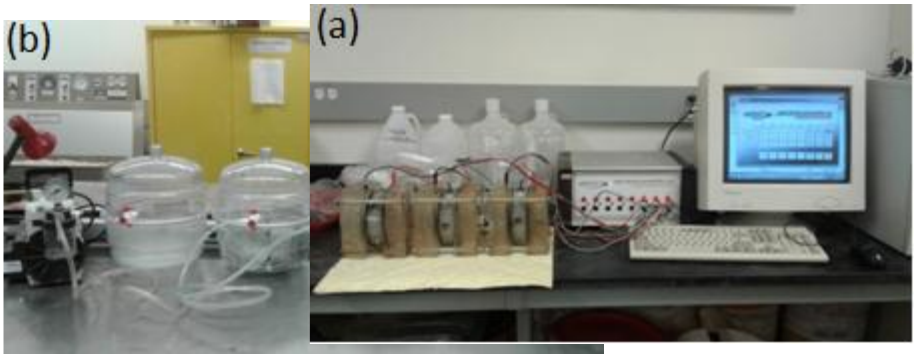

Figure (5) Rapid chloride permeability test (RCPT)
(a) Set up during test running, (b) Set up of air extraction from concrete specimens.

3. Preliminary results and discussion

3.1. Compressive Strength

Figure 6 shows compressive strength results at 28 and 56 days for all tested mixtures. Compressive strength increased for all tested mixtures over time. In addition, results showed that mixtures containing SF reveal an increase in strength compared to mixtures without SF. For instance, compressive strengths for mixtures C and S at 28-days were 47.5, and 54.7 MPa, respectively. This due to the pozzolanic effect encouraged by SF addition (Nevillie 2002, Mehta et al., 2006, and Poon et al., 2006). Generally, the compressive strength decreased due to the addition CRA in mixtures with and without SF. The reduction can be attributed to the increase in air content, low CRA stiffness and lower bond between cement paste and CRA (Issa et al., 2013, Ganesan et al., 2013, Kardos et al.2015, and Gupta et al., 2016).

Mixtures with SF reveal an increase in strength compared to those mixtures without SF. For instance, the compressive strengths for mixtures CR and SR showed a reduction in by about 29.5%, and 26% than the control mixtures C, and S at 28 days, respectively. From the test results and above explanation, it's clear the target strength at 28 days achieved by using 10% CRA with 10% SF, which encourage usage of CRA for many concrete applications.

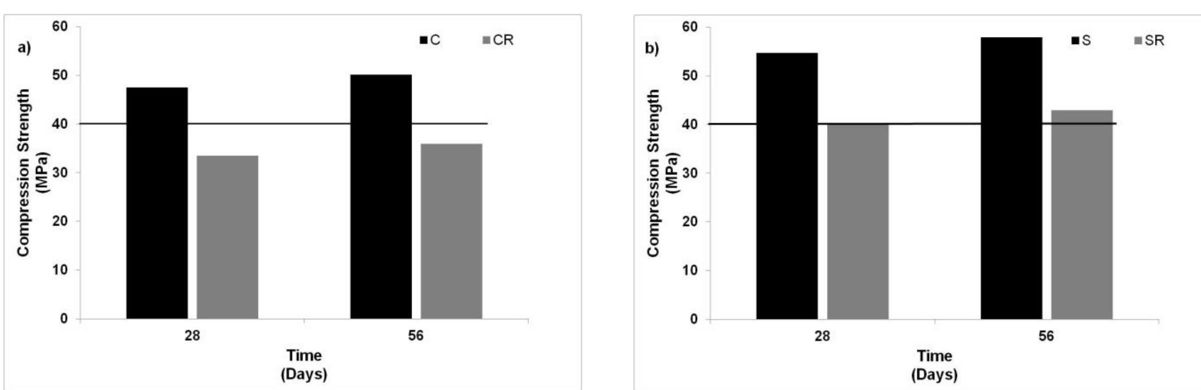

Figure (6) Compressive strength of tested mixtures
a) without SF and b) with SF addition

3.2. Tensile Strength

Tensile strength results followed the same trend as compressive strength as shown in **Fig. 7 (a,b)**. Generally, tensile strength increased with time. Moreover, the results of mixtures incorporating SF exhibited a higher increase in tensile strength than that of mixtures without SF. For instance, tensile strengths for mixtures C and S at 28-days were 4.5, and 6.1 MPa, respectively. The tensile strength decreased due to the addition CRA with and without SF. The decreased caused due to the rough surface, and nonpolar property properties of CRA, that fend off the water, as a result, cracks around CRA particles and presence of cavities increased (Turatsinze et al., 2008, Turatsinze, et al., 2016, and Thomas et al., 2016).

The partial replacement of 10% CRA, mixtures with SF exhibited an increase in tensile strength compared to those mixtures not contains SF. For example, the tensile strengths of mixtures CR and SR showed a reduction in by about 31.1, and 23.8% than mixtures C, and S at 56 days respectively.

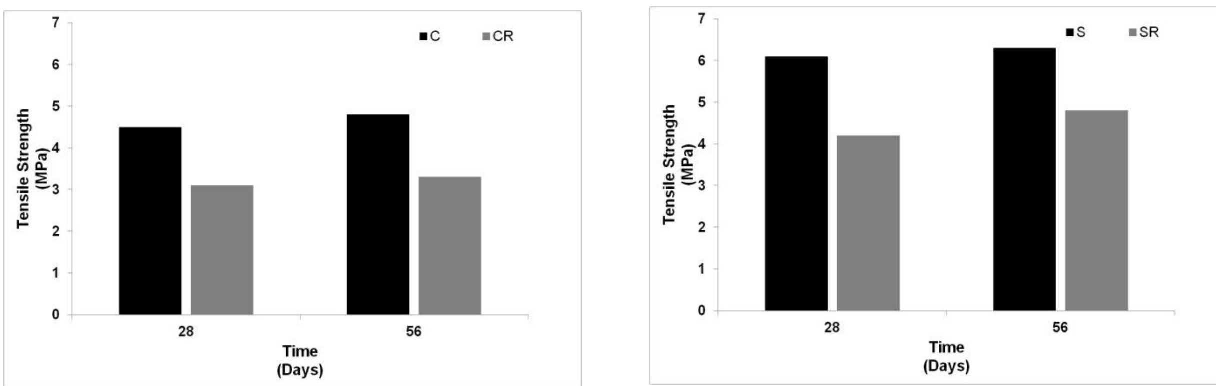

Figure (7) Tensile strength for tested mixtures
a) without SF and b) with SF addition

3.3. Modulus of Elasticity

The elasticity and response of concrete to loads was evaluated by applying 40% from the 28 day compressive strength on all concrete mixture. The modulus of elasticity was decreased for concrete mixtures incorporating CRA, this can be attributed due adding CRA of high elastic property in comparison to a high rigid composed material (concrete). For example, the concrete mixture CR produced modulus of elasticity lower than the control mixture C by about 27% at 56-days. On the other hand, the concrete mixture SR that contains 10% SF acquire modulus of elasticity lower than the S mixture by about 24% at the same age (i.e., 56-days) as represented in Fig.(8).

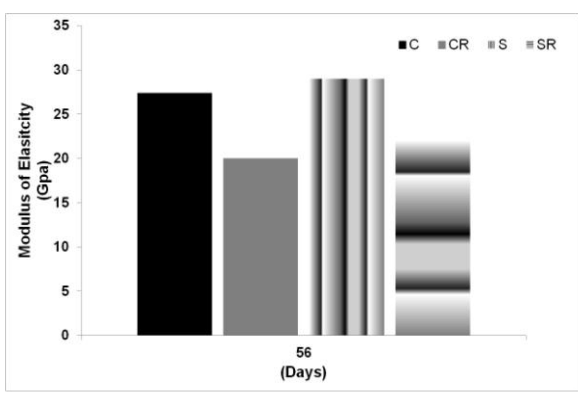

Figure (8) Modulus of elasticity for tested mixtures at 56-days

3.4. Ultrasonic Pulse Velocity

The measurements of UPV were conducted weekly on all tested mixtures. The results illustrated in **Fig. (8)** exhibit that the wave speed increased over time for all concrete mixtures due to hydration that decreases the concrete porosity. For instance, the speed in mixture C developed from 3922 to 4291 to 4408m/s at 1, 28, and 56 days respectively. The mixture incorporating SF reveals a lower decrease in wave speed by about 4% than that mixtures without SF. Finally, the partial replacement of CRA by 10% causing a reduction in wave speed in mixtures CR, and SR by about 14, and 16% from the mixtures C, and S respectively. This reduction in waves attributed due to the increase of air voids that retards the wave travels (Kardos et al., 2015).

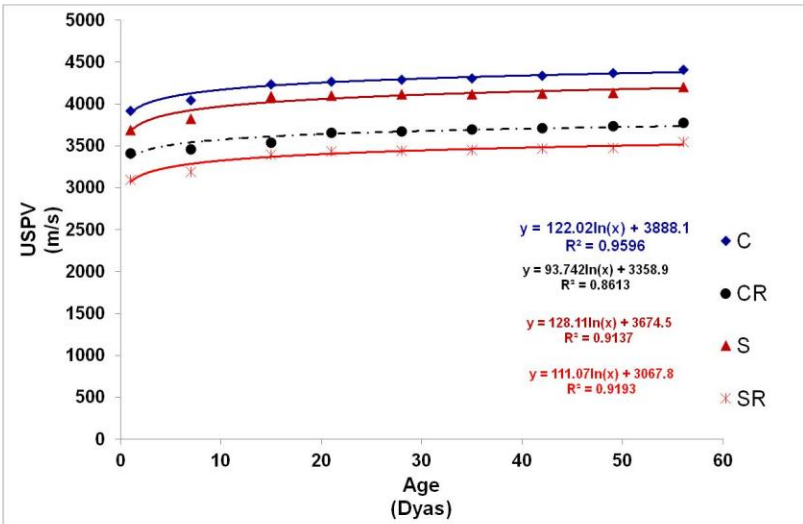

Figure (8) Ultrasonic pulse velocity for tested mixtures

3.5. Surface Resistivity (SR)

The electrical resistivity is considered a crucial property of concrete that provides information on the concrete capability to withstand the ionic penetration (Rupnow et al., 2011). The higher resistivity, the higher the resistance to ionic penetration. **Figure (9)** shows the surface resistivity for all tested mixtures; SR with and without SF increase over time. Concrete mixtures without SF (either C or CR) can be classified in the low range, while mixtures S and SR can be classified in the low to very low range according to AASHTO TP 95-11. It is apparent the concrete resistance affected by dense microstructure produced due to adding SF.

The partial replacement of CRA caused a slight increase in SR by about (4-7%) of concrete mixtures not contains SF. On the other hand, the CRA caused a significant reduction in SR of mixtures incorporating SF by about (22-28%), but the SR still in the low range after the third week.

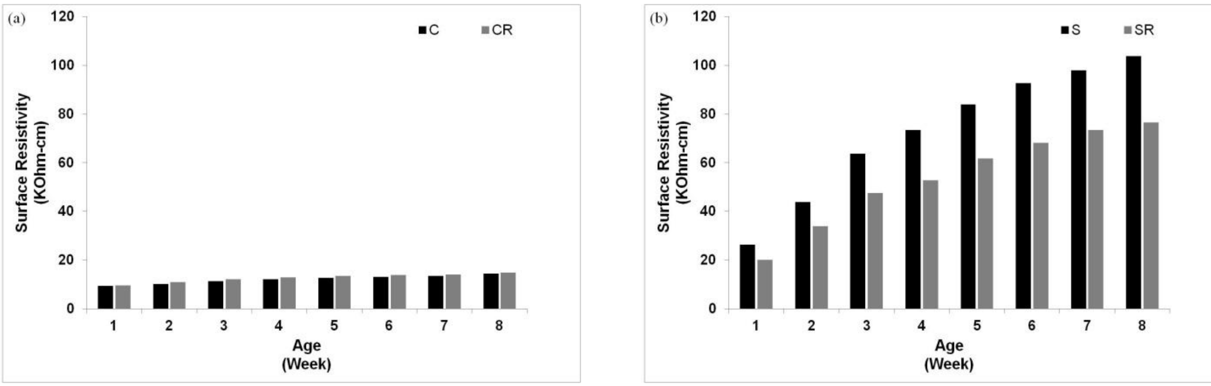

Figure (9) Ultrasonic pulse velocity for tested mixtures
a) without SF and b) with SF addition

3.6. Rapid Chloride Permeability Test (RCPT)

The Rapid Chloride Permeability Test (RCPT) was performed on 28, and 56 days for all tested mixtures to represent the concrete resistance to infiltration of chloride ions. **Figure 10 (a,b)** represents the total charge passing over 6 hours. Generally, the permeability for all tested mixtures decreased with age due to development of hydration and concrete becoming denser. In addition, the partial replacement of SF by 10% revealed a significant effect on the total charge passed as the concrete was less porous, reducing the rate of chloride ions transfer and total passing charge. The replacement of CRA by 10% acquired lower permeability according to ASTM C1202 with and without SF at the testing ages. For example, the total charge passed at 28 days of mixture CR recorded 1755 Coulombs.

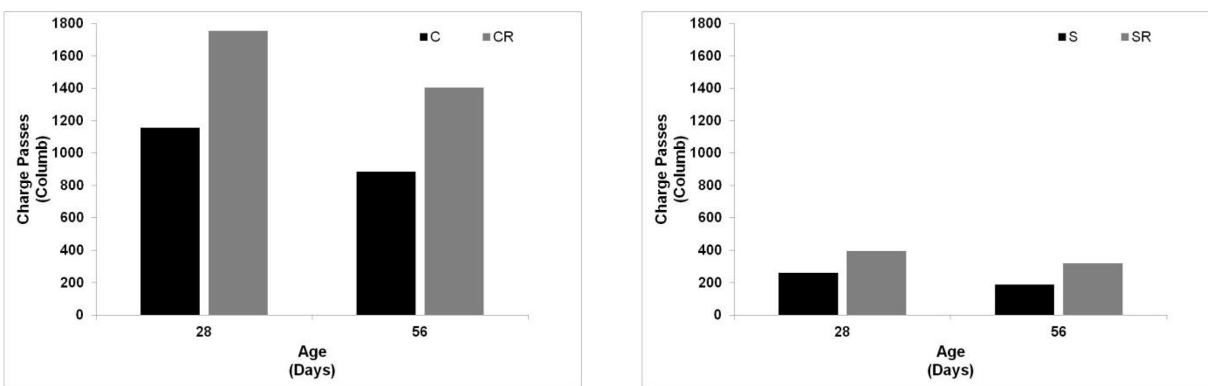

Figure (10) Rapid Chloride Permeability Test for tested mixtures

a) without SF and b) with SF addition

4. CONCLUSION

Four concrete mixtures were cast to evaluate 10% CRA partial replacement effect with and without 10% SF on the electrical, mechanical, and permeability properties.

1. The test results indicated the partial replacement of CRA caused a reduction in concrete compressive, and tensile strengths with and without SF.
2. The concrete mixtures SR incorporating 10% CRA and 10% SF met the target strength at 28 days.
3. CRA reduced the concrete mixtures Modulus of elasticity, and concrete became less stiff.
4. Ultrasonic wave speed in mixtures CR and SR reduced by about 14, and 16% from C, and S mixtures respectively due to CRA.
5. Surface resistivity was slightly affected by CRA in the mixtures not containing SF, while there is a significant effect by about (22-28%) reduction in SR for mixtures incorporating SF by about (22-28%).
6. Concrete permeability reduced for all mixtures with age. Moreover, mixtures incorporating 10% SF and 10% CRA as partial replacement of cement and sand acquired the lower permeability according to ASTM C1202, respectively.

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References

AASHTO, TP95. "95-11 “Standard Method of Test for Surface Resistivity Indication of Concrete’s Ability to Resist Chloride Ion Penetration.”." *AASHTO Provisional Standards, 2011 Edition* (2011).

ASTM, C. "Standard test method for electrical indication of concrete’s ability to resist chloride ion penetration, 1202." *Philadelphia, PA: Annual Book of ASTM Standards* (2006).

Standard, A. S. T. M. "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." *ASTM International* (2016).

ASTM, C. "Standard Specification for Concrete Aggregates." *Philadelphia, PA: American Society for Testing and Materials*(2003).

ASTM, C. "39. 2005." *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM International. West Conshohocken, PA* (2005).

ASTM, C. "496/C 496M.(2011)." *Standard test method for splitting tensile strength of cylindrical concrete. West Conshohocken, PA: ASTM*.

CSA. Cementitious Materials Used in Concrete. Canadian Standard association, (2008b)

Ganesan, N., J. Bharati Raj, and A. P. Shashikala. "Flexural fatigue behavior of self compacting rubberized concrete." *Construction and Building Materials* 44 (2013): 7-14.

Güneyisi, Erhan, Mehmet Gesoğlu, and Turan Özturan. "Properties of rubberized concretes containing silica fume." *Cement and concrete research* 34, no. 12 (2004): 2309-2317.

Gupta, Trilok, Sandeep Chaudhary, and Ravi K. Sharma. "Mechanical and durability properties of waste rubber fiber concrete with and without silica fume." *Journal of Cleaner Production* 112 (2016): 702-711.

Holmes, Niall, Alex Browne, and Christopher Montague. "Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement." *Construction and Building Materials* 73 (2014): 195-204.

Issa, Camille A., and George Salem. "Utilization of recycled crumb rubber as fine aggregates in concrete mix design." *Construction and Building Materials* 42 (2013): 48-52.

Kardos, Adam J., and Stephan A. Durham. "Strength, durability, and environmental properties of concrete utilizing recycled tire particles for pavement applications." *Construction and Building Materials* 98 (2015): 832-845.

Monteiro, Paulo. *Concrete: microstructure, properties, and materials*. McGraw-Hill Publishing, 2006.

Nevillie, A. M. "Properties of Concrete–Fourth and Final Edition." (2002).

Rupnow, Tyson, and Patrick Icenogle. "Surface resistivity measurements evaluated as alternative to rapid chloride permeability test for quality assurance and acceptance." *Transportation Research Record: Journal of the Transportation Research Board* 2290 (2012): 30-37.

Thomas, Blessen Skariah, and Ramesh Chandra Gupta. "A comprehensive review on the applications of waste tire rubber in cement concrete." *Renewable and Sustainable Energy Reviews* 54 (2016): 1323-1333.

Turatsinze, A., and M. Garros. "On the modulus of elasticity and strain capacity of self-compacting concrete incorporating rubber aggregates." *Resources, conservation and recycling*52, no. 10 (2008): 1209-1215.

Turatsinze, Anaclet, Michel Measson, and Jean-Philippe Faure. "Rubberised concrete: from laboratory findings to field experiment validation." *International Journal of Pavement Engineering* (2016): 1-10.