CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

MECHANICAL AND DURABILITY PROPERTIES OF RUBBERIZED RECYCLED AGGREGATE CONCRETE

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Abstract: Recycled concrete aggregate as a construction material is being researched for many years and as a result, many standards have accepted it as a partial or full replacement of natural aggregate (coarse and fine) in the production of structural and non-structural concrete. On the other hand, use of crumb rubber (recycled rubber) as substitution of fine aggregate has also been studied by many researchers. The aim of this paper is to study the mechanical and durability properties of rubberized recycled aggregate concrete. Mechanical properties such as compressive, tensile and flexural strength were investigated as well as resistance to chloride ion ingress and freeze-thaw for its durability. For this purpose, three replacements levels of recycled concrete coarse aggregate (0%, 50% and 100%) and crumb rubber (0%, 10% and 20%) were used in concrete along with 0.1% of recycled steel tire wires. Overall, this study demonstrates the potential of using rubberized recycled aggregate concrete as sustainable construction material.

1 INTRODUCTION

The era of modernization and industrialization along with bringing facilities to human life also raises loads in the landfills, which is a major threat to all the species of this planet. The most alarming about landfills is pilling of non-biodegradable materials like plastics, metals scrap, glasses, rubber tires and construction and demolition waste (C&D waste). With the passage of time and increased awareness in the Research & Development sector, systems and protocols have been developed for fully of partly recycling of the non-biodegradable waste. However, the rate of recycling is much lower than their generation rate. To illustrate, 9 million tons (approx.) of C&D waster per annum is generated by the construction industry in Canada (Yeheyis, et al., 2013) and only 30% of it is recovered. This recovery rate is very low in comparison to the Netherlands and Taiwan i.e. 98% and 91% respectively (Tam, et al., 2018). Moreover, 52% by weight of C&D waste is composed of concrete (Abbas, et al.,2007), which has high sustainable potential of recycling in form of recycled concrete aggregate (RCA) and reusing in concrete as replacement of natural coarse aggregate (NCA) (Yeheyis, et al., 2013).

On the other hand, 30 million tons of scrap tires are disposed to landfills per annum in North America (Kim, Yoon, and Yoon 2011). These stockpiled tires, in addition, to serve as breeding colonies of pests, are potential sites of trigging massive fires such as fire break out in Iowa city landfill in 2012 and Hagersville in 1990. These fires burnt out 7.5 acres of the landfill (Hermiston 2019) and 12 to 14 million tires in 17 days (Saskatchewan Waste Reduction Council, 2019), respectively and caused serious environmental risks. Besides, disposed tires are reported to decrease landfill space as they entrapped air and hamper future landfill reclamation (United States Fire Administration 1998). Also, contamination by Zinc leachate is associated with scrap tires and tire-derived products like crumb rubber (CR), on their interaction with the ground (Rhodes, et al.,2012). Therefore, recycling of scrap tires in form of CR (shredded recycled tires after removal of steel tire wires) and adding them in concrete in replacement of natural fine aggregate- sand (NFA) is an effective environmental solution considering problems associated with tire disposal landfills and extraction of natural aggregates.

The use of RCA and CR in concrete has been investigated individually by many researchers for mechanical and durability properties (Etxeberria et al. 2007; Najim and Hall 2010; Kou and Poon 2012; Pedro, et al. 2014; Huda and Alam 2015; Meherier, et al, 2015; Richardson et al. 2016; Najjar, et al. 2016; Si, et al.2017; Dai et al. 2017; Verian, et al 2018), whereas very few researches have studied their combined effect on properties of concrete, term as rubberized recycled aggregate concrete (RRAC) (Henry et al. 2012; Su et al. 2014; Tamanna,et al. 2017; Aslani, et al. 2018). To elaborate, RRAC is a concrete modified by replacement of NCA by RCA and NFA by CR. This paper discusses the outcome of the experimental investigation of partial (50%) and full (100%) substitution of RCA, and 10% and 20% replacement of NFA by CR on mechanical and durability properties of concrete, outlined in next section.

2 METHODOLOGY

2.1 Materials and mix proportions

This experimental study was conducted on six mixtures designed according to CSA standard (CSA 2014) with GU cement, NCA, RCA, silica sand (i.e. NFA) and CR as main constituents. In addition to these, 0.1% (volumetric percentage of mix) recycled steel tire wires (Fibers) (density 4664 kg/m^3 and length 2-3 cm), water reducing admixture and air entertaining admixture were used. In particular, all the materials used were in accordance with CSA standard (CSA 2014) and admixtures were in accordance with ASTM standard; water reducing admixture as per ASTM C494/C494M(ASTM 2017a) and air entertaining admixture as per ASTM C260/C260M (ASTM 2010). Furthermore, three replacement levels of RCA and CR was employed by weight replacement of NCA by RCA (i.e. 0, 50 and 100%) and volumetric replacement of NFA by CR (i.e. 0,10 and 20%). RCA was collected from a commercial concrete recycler in Vancouver to outreach commonly available RCA in British Columbia conforming to CSA standard (CSA 2014). RCA was washed and surface dried before mixing and amount of mixing water was adjusted considering the water absorption of RCA. In addition to this, the mixtures were designed for target strength of 35 MPa at 28 days, exposure class C-2, with effective w/c ratio of 0.31 (CSA 2014). Mix design for 1m^3 of concrete along with nomenclature of mixtures is given in Table 1, which was provided by the industrial partners. To elaborate, throughout in the text $C_{50}R_{10}$ means a mixture with 50% replacement of NCA by RCA and 10% replacement of NFA by CR with (F) stands for the presence of fibers in the mixture. Besides, C_0R_0 is considered as the control mixture in this study with no RCA and CR content.

Table 1: Concrete mixture constituents per cubic meter

Constituent	**C_0R_0**	**$C_{50}R_{10}$**	**$C_{100}R_{20}$**	**C_0R_0F**	**$C_{50}R_{10}F$**	**$C_{100}R_{20}F$**
Cement (kg)	385	385	385	385	385	385
NCA (kg)	1142	571	0	1142	571	0
RCA (kg)	0	571	1142	0	571	1142
NFA (kg)	633	570	507	633	570	507
CR (kg)	0	29	57	0	29	57
Water (kg)	119	120	123	120	121.5	124
Fibers (kg)	0	0	0	4.6	4.6	4.6
Water reducer (ml)	3140	3440	3850	3140	3440	3850
Air entertainer (ml)	192	192	192	192	192	192

Moreover, the surface of CR is hydrophobic due to the presence of Zinc and Silicon (Meherier, 2016) and its treatment with Sodium Hydroxide (NaOH) solution results in relatively rougher surface as discussed by Mohammadi et al., (2016). With regard to this, a recent study was conducted by Tamanna et al., (2017) in which CR was treated with 20% NaOH solution to enhance its surface bonding, and the same was used for this study. Treatment of CR with NaOH comprised of washing it with tap water then immersing in 20% NaOH solution for 30 min followed by rinsing with tap water (by ponding) and draining until the pH of drained water reached to 7 and finally air drying (Tamanna et al., 2017). Furthermore, to investigate the effect of NaOH treatment on bonding characteristics of CR particles, Energy Dispersive Spectroscopy (EDS) and backscattered scanning electron microscopy (BSEM) imaging were performed. The results of these two tests are presented in Table 2 and Figure 1, respectively. In Table 2, comparison is also made between chemical properties of untreated CR reported by Meherier (2016) and treated CR with 20% NaOH. It can be seen that treatment of CR with 20% NaOH solution resulted in 96% reduction of Silicon and 76% of Zinc content, their presence is the main cause of hydrophobic behaviour and poor bonding. Similarly, images captured by BSEM at 500x magnification show a well embedded and properly bonded rubber particles in the matrix.

Table 2: Comparison of chemical properties of crumb rubber by EDS

	Weight (%)	
Elements (Symbol)	**Untreated CR (Meherier, 2016)**	**Treated CR**
Carbon (C)	69.95	88.88
Oxygen (O)	20.93	8.65
Sodium (Na)	0.38	0.49
Magnesium (Mg)	0.23	0.06
Aluminum (Al)	0.71	-
Silicon (Si)	1.53	0.09
Sulfur (S)	1.42	1.08
Potassium (K)	0.12	0.03
Calcium (Ca)	0.22	0.26
Iron (Fe)	2.43	-
Copper (Cu)	0.15	-
Zinc (Zn)	1.91	0.46

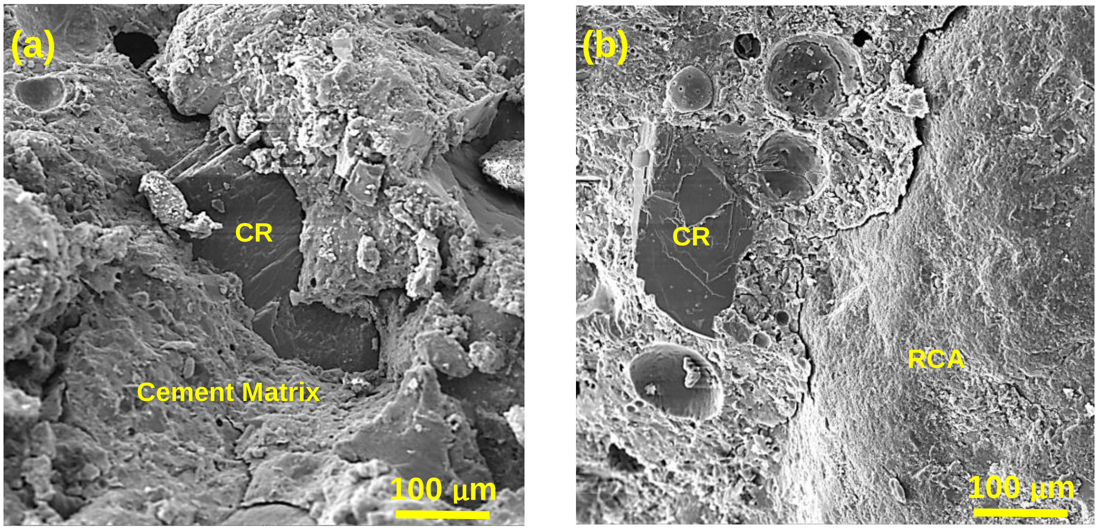

Figure 1: BSEM images of CR particles at 500x magnification (a) Interlocking of CR in matrix, (b) Bonding of CR with matrix

Engineering properties of coarse aggregates, as well as gradation characteristics of both coarse and fine aggregates were tested according to CSA A23.2- 2A(CSA 2014), and are summarized in Table 3 and Figure 2. As RCA is obtained from crushing of hardened (waste) concrete, it is composed of NCA and hardened mortar attached to it. Bulk density and specific gravity of RCA are lower than NCA due to the presence of this attached mortar (AM), which can also be seen from Table 3. In contrast, AM is the cause of 2.7 times increased absorption capacity of RCA then NCA due to its relative porous structure as shown in Table 3. However, the gradation curve of NCA and RCA are within CSA upper and lower limits (CSA 2014), presented in Figure 2. Similarly, satisfactory gradation characteristics are exhibited by NFA and CR.

Table 3: Basic engineering properties of coarse aggregates

Properties	**NCA**	**RCA**	**NFA**	**CR**
Bulk density (kg/m^3)	1588	1455	-	-
Bulk dry specific gravity	2.62	2.39	-	-
Bulk SSD specific gravity	2.66	2.50	2.6	1.152
Apparent specific gravity	2.74	2.68	-	-
Absorption capacity (%)	1.66	4.42	1.52	1.2

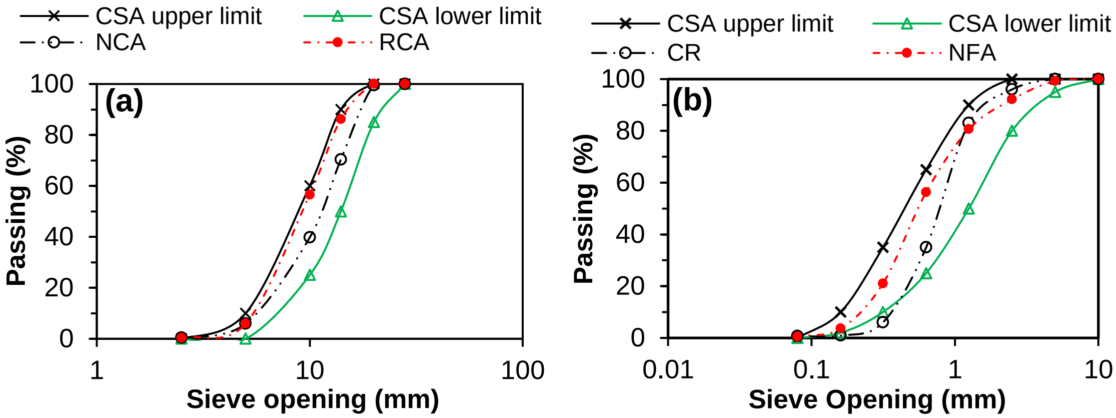

Figure 2: Sieve analysis of (a) coarse, and (b) fine aggregates.

2.2 Specimen and testing

As this research was conducted to study the mechanical as well as durability properties of RRAC, compressive, tensile, and flexural strength were evaluated under mechanical properties. Whereas, freeze-thaw resistance and rapid chloride penetration test (RCPT) were performed to determine the durability of RRAC. For each mixture, fourteen 100Φ×200 mm cylindrical specimens were casted to evaluate the compressive strength at 7, 28 and 56 days, split tensile strength of concrete at 28 days, preparing specimens for testing potential of chloride ion ingress. The standards followed to perform these tests were CSA A23.2-9C and CSA A23.2-13C (CSA 2014), respectively. Further, 150×150×530 mm prisms were prepared to determine flexural strength at 28 days as per CSA A23.2-8C (CSA 2014), while 76×102×406 mm prisms were casted for freeze and thaw resistance testing according to ASTM C666 procedure A (ASTM 2015). Freeze and thaw resistance test is a rapid test in which concrete prisms after 14 days of curing are subjected to cyclic temperature variation from -18°C to 4°C and the results are reported after each set of 36 cycles. However, for this study, only weight change of specimens is presented as a measure for freeze-thaw resistance. Besides, rapid chloride permeability test (RCPT) was performed on cylindrical discs of diameter 100mm and thickness of 50mm, which gives an indication of concrete's resistance to chloride ion penetration. Concrete discs were obtained by casting cylinders of 100Φ×200mm and cutting them to the required thickness of 50mm using concrete cutter after 28 days of curing. Discs having one casted face and one cut face were selected to undergo this test. Subsequently, these discs were conditioned and tested in accordance with ASTM C1202 (ASTM 2017b). Overall, 84 cylinders and 36 prisms were casted according to CSA A23.2-3C (CSA 2014) and cured as per CSA A23.2-3C (CSA 2014) to complete the tests mentioned above. Moreover, slump and air content of RRAC mixtures were also measured following CSA A23.2-4C and CSA A23.2-5C (CSA 2014), respectively.

3 RESULTS AND DISCUSSIONS

3.1 Fresh concrete properties

Slump and air content were the two properties investigated for fresh concrete properties. All of the six mixtures (with and without fibers) were designed for target slump of 100±25mm and air content within 5-8%, according to CSA A23.1Table 4 (CSA 2014) guidelines for exposure category C-2. From the results of these tests tabulated in Table 4, it can be observed that all the mixtures comply with the designed values except C_0R_0F with an air content of 4.5%. Moreover, slump value decreases with an increase in rubber and RCA content because of high water absorption of RCA. Addition of fibers also reduces the workability of concrete as the mixture becomes relatively more dense, while the percentage of air content in mixtures is not much affected.

Table 4: Slump and air content of the mixtures

Mixture ID	**Slump (mm)**	**Air content (%)**
C_0R_0	125	5.4
$C_{50}R_{10}$	120	5.3
$C_{100}R_{20}$	105	6.4
C_0R_0F	105	4.5
$C_{50}R_{10}$ F	100	5.8
$C_{100}R_{20}$ F	90	6.7

3.2 Mechanical properties

The effects of using a combination of RCA, treated CR and fibers on compressive, tensile and flexural strength of RRAC are discussed in sub-sections.

3.2.1 Compressive strength

The compressive strength test results performed at 7, 28 and 56 days are illustrated in Figure 3. As can be seen, compressive strength of concrete was declined when the combination of RCA and CR was employed at all test ages. This is due to high compressibility of rubber particles causing large strains and initiating failure. Najjar, et al. (2016) and Tamanna et al. (2017) have reported similar reduction trends in compressive strength of RRAC. Further, except $C_{50}R_{10}$ and $C_{50}R_{10}F$ all mixtures reached the target strength of 35 MPa at 28 days. After 28 days till 56 days of curing, there was not much improvement in compressive strength of the mixtures, however, $C_{50}R_{10}$ and $C_{50}R_{10}F$ accomplished the target strength by 56 days. Moreover, addition of fibers in the mixtures has a profound effect on compressive strength because of its bridging action of transferring force after initial development of cracks. Notably, compressive strength of C_0R_0F was increased by 59% at 7 days, $C_{100}R_{20}F$ by 31% at 28 days and $C_{50}R_{10}F$ by 20% at 56 days in comparison to C_0R_0, $C_{100}R_{20}$, $C_{50}R_{10}$ respectively.

3.2.2 Tensile and Flexural strength

The tensile and flexural strength of RRAC tested at 28 days are presented in Figure 4. It can be observed that tensile and flexural strength followed the same descent trend as the case of compressive strength on the addition of RCA, CR and fibers. For tensile strength, the decrease was from 3.97 MPa to 2.46 MPa for RRAC without fibers and was 4.52 MPa to 3.95 MPa for fiber reinforced RRAC, with augmenting content of RCA from 0 to 100% and CR from 0 to 20%, respectively. Whereas, for flexural strength, there was a decrease of only 1 MPa for $C_{100}R_{20}F$ and 0.23 MPa for $C_{50}R_{10}F$ with reference to control mixture. Further, flexural strength was reduced by 32% for $C_{50}R_{10}$ and 6% for $C_{100}R_{20}$, reciprocally. On the other hand, tensile strength of $C_{100}R_{20}$ is in contradiction to its flexural strength, which seems to be due to variation in compaction levels of cylinders and can be supported by large standard deviation of tensile strength data.

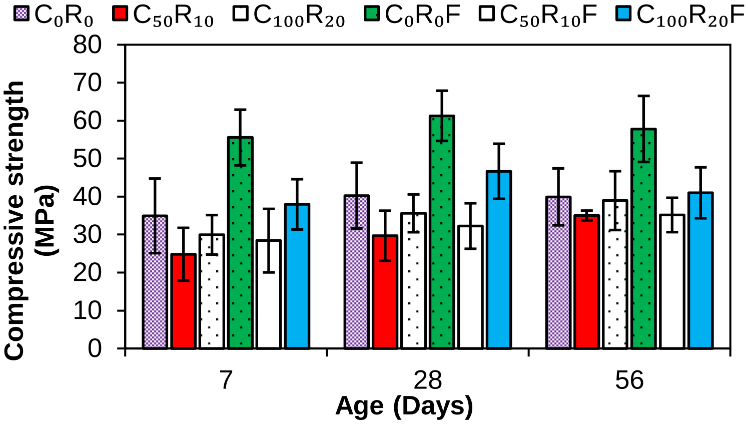

Figure 3: Compressive strength of RRAC

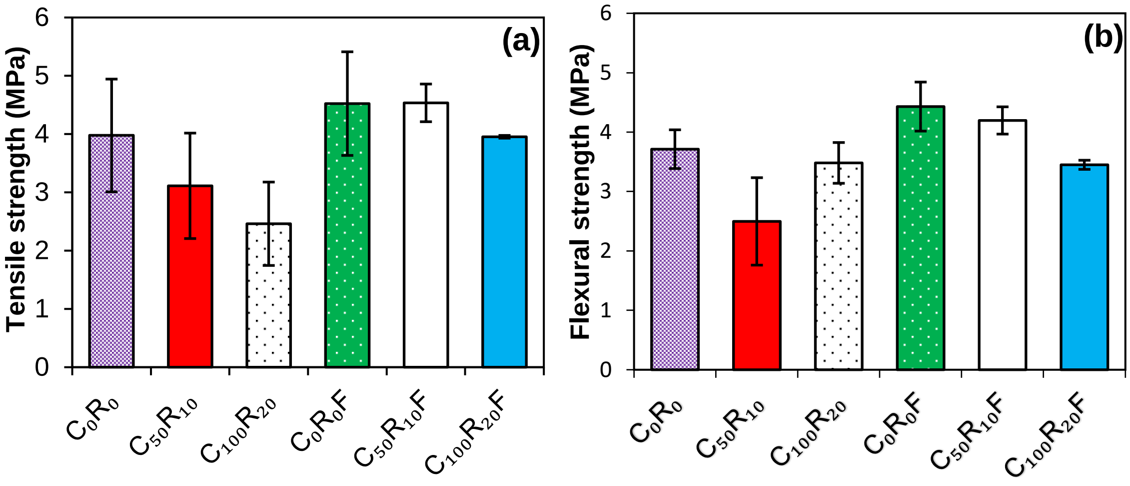

Figure 4: (a)Tensile strength of RRAC (b) Flexural strength of RRAC

3.3 Durability properties

3.3.1 Freeze-thaw resistance

Freeze-thaw resistance was measured for 216 cycles because of time limitations. The effect of freeze-thaw on RRAC with an increase in percentage replacement of RCA and CR were discussed in terms of percentage weight change and are presented in Figure 5. To elaborate, minimum change in weight with an increase in freeze-thaw cycles is representation of resistant concrete. It is clear from Figure 5 that resistance of mixtures was enhanced with the increase of CR content due to its non-shrinkage and hydrophobic nature. Similar results, presented as R_0, R_{10} and R_{20} in Figure 5, were reported by Meherier (2016) for the study conducted on freeze-thaw resistance of conventional concrete with 10% and 20% replacement of NFA by CR. Moreover, presence of RCA in the mixtures reduced the resistance to freeze-thaw exposure, which can be observed from the upward trend of the graphs after 108 cycles for each percentage substitution of RCA. On the other hand, addition of fibers also augments this resistance by obstructing the development of cracks by freeze-thaw cycles(Najjar et al., 2016).

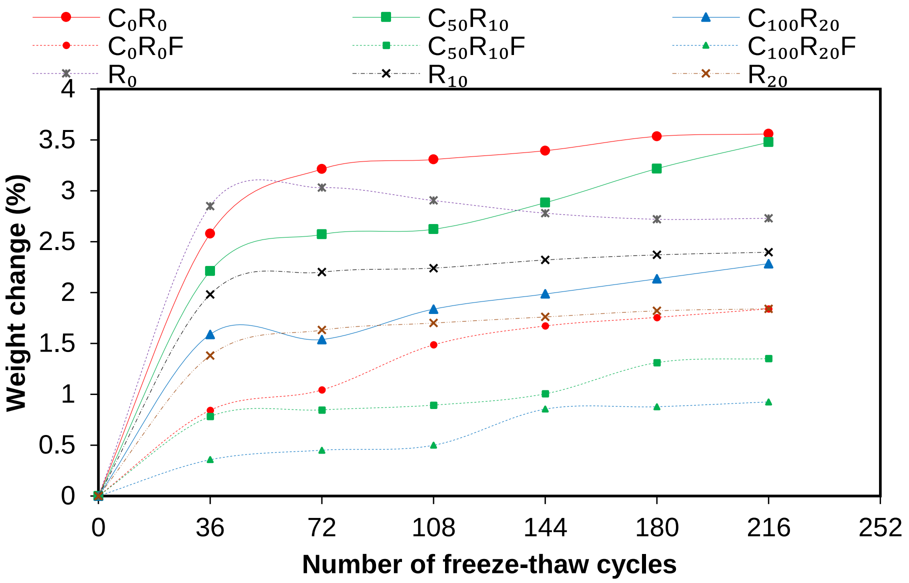

Figure 5: Freeze-thaw resistance of RRAC subjected to 216 cycles.

3.3.2 Rapid chloride penetration test

Resistance to chloride penetration was measured in terms of electric charge passed through concrete discs of 50mm thickness and was reported in terms of permeability class in Table 5 as per ASTM 1202 (ASTM 2017b). Further, this test was conducted only on control mixture C_0R_0 and $C_{50}R_{10}$ with and without fibers because of variation in test results on the addition of CR and fibers. It can be seen from Table 5 that incorporation of CR in the mixture decreased the permeability as rubber particles hurdle the formation of continuous penetration passage (Meherier 2016). Whereas, introducing RCA and fibers, being porous and conductive in nature decreased permeability and lower the permeability class from “Low” to “Moderate”. As combinations of materials with varying effects on permeability were used, this test is not conclusive for this type of concrete and needs further detailed investigation using some advanced permeability tests.

Table 5: RCPT results in terms of Coulomb passed and permeability class

Mixture ID	Charge passed (Coulomb)	Permeability Class
C_0R_0	3127	Moderate
$C_{50}R_{10}$	1019	Low
C_0R_0F	1462	Low
$C_{50}R_{10}F$	2016	Moderate

CONCLUSIONS

Based on the results of this study investigating the combined effect of RCA and CR on properties of concrete with the addition of recycled steel tire wires, following conclusions can be drawn:

- Rubberized recycled aggregate concrete showed a reduction in compressive strength with respect to control mixture. However, performance of $C_{100}R_{20}$ is within acceptable limits with 56 days compressive strength very close to control mixture. Moreover, tensile and flexural strength has no significant decrease with increase in RCA and CR combination in concrete when tested at 28 days.

- Treatment of CR with 20% Sodium Hydroxide solution resulted in better interlocking of CR in the matrix as confirmed from EDS analysis and BSEM images.

- Addition of fibers has augmented the mechanical properties of RRAC as well as freeze-thaw resistance by bridging and hindering the development of the cracks, respectively.

- Permeability of RRAC concrete needs a further detailed investigation to conclude the effect of using RCA, CR and fibers combination in concrete with the help of some advanced permeability tests.

This study is a preliminary investigation on the combined effect of two recycled materials in concrete replacing both coarse and fine aggregate simultaneously, which need to be further researched for at least stress strain behaviour and modulus of elasticity for mechanical properties and in-depth for durability performance against destructive exposures.

ACKNOWLEDGEMENT

The authors are thankful to NSERC-CRD grant for funding this project, and Liberty tire recycling company and Kon Kast products Ltd for providing the required materials.

REFERENCES

Abbas, A.; Fathifazl, G.; Isgor, O. B.; Razaqpur, A. G.; Fournier, B.; Foo, S. 2007. “Environmental Benefits of Green Concrete.” In *2006 IEEE EIC Climate Change Technology Conference, EICCCC 2006*. doi:10.1109/EICCCC.2006.277204.

Aslani, Farhad, Guowei Ma, Dominic Law Yim Wan, and Gojko Muselin. 2018. “Development of High-Performance Self-Compacting Concrete Using Waste Recycled Concrete Aggregates and Rubber Granules.” *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2018.02.074.

ASTM. 2010. “Standard Specification for Air-Entraining Admixtures for Concrete.” *ASTM C260/C260M—10a*.

ASTM. 2017a. “Standard Specification for Chemical Admixtures for Concrete.” *ASTM C494/C494M-17*.

ASTM. 2017b. “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration.” *ASTMC1202-17a*, 1–8. doi:10.1520/C1202-12.2.

CSA. 2014. “Concrete Materials and Methods of Concrete Construction/Methods of Test and Standard Practices for Concrete. Toronto (Ontario, Canada).” *CSA A23.1/23.2*, no. September 2015.

Dai, Qingli, Xiao Sun, Chao Lu, Shuaicheng Guo, and Ruizhe Si. 2017. “Evaluation of Properties and Performance of Rubber-Modified Concrete for Recycling of Waste Scrap Tire.” *Journal of Cleaner Production* 148. Elsevier Ltd: 681–89. doi:10.1016/j.jclepro.2017.02.046.

Etxeberria, M, E Vázquez, A Marí, and M Barra. 2007. “Influence of Amount of Recycled Coarse Aggregates and Production Process on Properties of Recycled Aggregate Concrete” 37: 735–42. doi:10.1016/j.cemconres.2007.02.002.

Federal Emergency Management Agency, and United States Fire Administration. 1998. “Scrap and Shredded Tire Fires,” 61. http://www.usfa.fema.gov/downloads/pdf/publications/tr-093.pdf.

Henry, M., H. Yamashita, T. Nishimura, and Y. Kato. 2012. “Properties and Mechanical-Environmental Efficiency of Concrete Combining Recycled Rubber with Waste Materials.” *International Journal of Sustainable Engineering*. doi:10.1080/19397038.2011.569584.

Hermiston, Lee. 2019. “After 15 Days, Landfill Fire Is Extinguished.” *Iowa City Press Citizen*. Accessed March 14. https://pqasb.pqarchiver.com/press_citizen/2684366631.html?FMT=ABS&date=Jun+12%2C+2012.

Huda, Sumaiya B., and M. Shahria Alam. 2015. “Mechanical and Freeze-Thaw Durability Properties of Recycled Aggregate Concrete Made with Recycled Coarse Aggregate.” *Journal of Materials in Civil Engineering* 27 (10): 04015003. doi:10.1061/(ASCE)MT.1943-5533.0001237.

Kim, Keun Soo, Yeo Won Yoon, and Gil Lim Yoon. 2011. “Pullout Behavior of Cell-Type Tires in Reinforced Soil Structures.” *KSCE Journal of Civil Engineering* 15 (7): 1209–17. doi:10.1007/s12205-011-1307-5.

Kou, S. C., and C. S. Poon. 2012. “Enhancing the Durability Properties of Concrete Prepared with Coarse Recycled Aggregate.” *Construction and Building Materials*. doi:10.1016/j.conbuildmat.2012.02.032.

Manal Najjar; Ahmed Soliman; Tareq Azabi; Moncef L.Nehdi. 2016. “GREEN SIDEWALKS USING SUSTAINABLE TWO-.” In *Resilient Infrastructure*. London: Candian Society of Civil Engineers.

Meherier, Md Salamah. 2016. "Investigation of Mechanical and Durability Properties of Cement Mortar and Concrete with Varying Replacement Levels of Crumb Rubber as Fine Aggregate." The University of British Columbia (Okanagan).

Meherier, Salamah, M. Shahria Alam, and Nemkumar Banthia. 2015. "Mechanical Behavior of Cement Mortar with Varying Replacement Level of Crumb Rubber." *The Fifth International Conference on Construction Materials*, no. August: 1–11.

Mohammadi, Iman, Hadi Khabbaz, and Kirk Vessalas. 2016. "Enhancing Mechanical Performance of Rubberised Concrete Pavements with Sodium Hydroxide Treatment." *Materials and Structures/Materiaux et Constructions*. doi:10.1617/s11527-015-0540-7.

Najim, K. B., and M. R. Hall. 2010. "A Review of the Fresh/Hardened Properties and Applications for Plain- (PRC) and Self-Compacting Rubberised Concrete (SCRC)." *Construction and Building Materials* 24 (11). Elsevier Ltd: 2043–51. doi:10.1016/j.conbuildmat.2010.04.056.

Pedro, D., J. De Brito, and L. Evangelista. 2014. "Influence of the Use of Recycled Concrete Aggregates from Different Sources on Structural Concrete." *Construction and Building Materials* 71. Elsevier Ltd: 141–51. doi:10.1016/j.conbuildmat.2014.08.030.

Rhodes, Emily P., Zhiyong Ren, and David C. Mays. 2012. "Zinc Leaching from Tire Crumb Rubber." *Environmental Science and Technology*. doi:10.1021/es3024379.

Richardson, Alan, Kathryn Coventry, Vikki Edmondson, and Eli Dias. 2016. "Crumb Rubber Used in Concrete to Provide Freeze-Thaw Protection (Optimal Particle Size)." *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2015.08.028.

Si, Ruizhe, Shuaicheng Guo, and Qingli Dai. 2017. "Durability Performance of Rubberized Mortar and Concrete with NaOH-Solution Treated Rubber Particles." *Construction and Building Materials* 153. Elsevier Ltd: 496–505. doi:10.1016/j.conbuildmat.2017.07.085.

Su, Haolin, Jian Yang, Gurmel S. Ghataora, and Samir Dirar. 2014. "Surface Modified Used Rubber Tyre Aggregates: Effect on Recycled Concrete Performance." *Magazine of Concrete Research*. doi:10.1680/macr.14.00255.

Tam, Vivian W.Y., Mahfooz Soomro, and Ana Catarina Jorge Evangelista. 2018. "A Review of Recycled Aggregate in Concrete Applications (2000–2017)." *Construction and Building Materials* 172. Elsevier Ltd: 272–92. doi:10.1016/j.conbuildmat.2018.03.240.

Tamanna, Kishoare; Pour, Sadaf M. ; Banthia, Nemkumar ; Alam, M. Shahria. 2017. "Experimental Investigation of Mechanical Properties of Rubberized Concrete Containing Recycled Coarse Aggregate." In , 1–11. Vancouver: CSCE Annual conferecne 2017.

"That Burning Sensation—Tire Fires." 2019. Saskatchewan Waste Reduction Council. Accessed March 14. http://www.saskwastereduction.ca/tires/fires.html.

Verian, Kho Pin, Warda Ashraf, and Yizheng Cao. 2018. "Properties of Recycled Concrete Aggregate and Their Influence in New Concrete Production." *Resources, Conservation and Recycling* 133 (February). Elsevier: 30–49. doi:10.1016/j.resconrec.2018.02.005.

Xiao, Jianzhuang, Wengui Li, and Chisun Poon. 2012. "Recent Studies on Mechanical Properties of Recycled Aggregate Concrete in China-A Review." *Science China Technological Sciences* 55 (6): 1463–80. doi:10.1007/s11431-012-4786-9.

Yeheyis, Muluken; Hewage, Kasun; Alam, M; Eskicioglu, Cigdem; Sadiq, Rehan. 2013. "An Overview of Construction and Demolition Waste Management in Canada: A Lifecycle Analysis Approach to Sustainability." *Clean Technologies and Environmental Policy* 15 (1): 81–91. doi:10.1007/s10098-012-0481-6.