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Evaluation of Concrete Strength Made with Recycled Aggregate

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Abstract: The construction industry consumes enormous quantities of concrete, which subsequently produces large amount of material waste during production and demolishing. As a result, the colossal quantity of concrete rubble is disposed in landfills. This paper, therefore, evaluated the feasibility of reusing waste concrete as recycled aggregate (RA) to produce concrete. The replacement levels were 20, 50, and 80% RA of normal coarse aggregate. Micro silica (MS) and fly ash (FA) were used as cementitious replacement material, however, the water-to-binder ratio (w/b) was kept constant at 0.31. A total of 44 specimens were used to evaluate the fresh and hardened properties. Concrete with 80% RA showed good workability and mechanical properties. The compressive strength of the concrete with 80% RA was 60 MPa at 28 days and 77 MPa at 56 days. Rapid chloride penetration test (RCPT) was also conducted, where the concrete with 80% RA had the lowest permeability.

Keywords: recycled aggregate; fly ash; silica fume; workability; compressive strength; tensile strength; RCPT

1. Introduction

Concrete is the most commonly used construction material with an estimated worldwide consumption of 31 billion tons in 2006 alone [1]. Concrete has numerous civil engineering applications, including roads, bridges, and dams. The main component of concrete is aggregate, which constitutes of about 75% of the total volume, making it the single most important component in determining the concrete's overall properties [2]. Producing concrete requires the procurement of the components, which modifies the natural resources of the concrete, making it environmentally hazardous [3]. Obtaining the aggregate obligates the disturbance of quarries, resulting in the decrease of scarce resources. A popular alternative would be the use of recycled aggregate (RA) obtained from waste concrete debris. In the last few decades, many structures in the Middle East were constructed during economic growth of the region [4]. However, these structures are being demolished because they have reached the end of their service life. The main reason for the demolitions is the lack of specification obedience for the structures at the time of construction. Demolishing the structures results in concrete rubble that can be further crushed to produce RA. These aggregates can be used in future concrete mixes, which is advantageous in different aspects. The main advantages of using RA are the alleviation of the environmental problems and the saving of the aggregate resources [5]. Statistics state that 70% of Dubai's 10,000 tons of daily general waste is the result of construction and demolition waste [6]. The environmental benefit of using RA is the preservation of the natural aggregate resources, which then eliminates procurement processes, such as excavation and crushing, and essentially reduces costs. Waste concrete produced from demolished old structures will be sent to landfills for disposal. Using this concrete as RA will save the cost of transporting and dumping the concrete [7]. Generally, incorporating RA into the concrete mix reduces the total impact compared to normal concrete production by 1–7% [8]. Recycled aggregate concrete (RAC) has been gaining interest in research and application [9–13]. Many countries have been utilizing RA as means of reducing the waste rubble and controlling the environmental impact. Estimates by the European Demolition Association dictate that about 200 million tons of concrete waste is produced annually across Europe. Of this quantity, 30% is being recycled to produce RAC. Some countries, such as Belgium and the Netherlands, recycle up to 90%, whereas other countries, such as Italy, recycle only 10% of the waste generated [5].

The effects of the RA in newly mixed concrete may vary due to several factors. One such factor is the source of the RA, in which some may lead to an increase in the concrete's properties [14]. For reinforced structures in areas under critical seismic conditions, Gonzalez and Moriconi [15] dictate that up to 30% RA replacement is adequate to maintain acceptable performance. Even though the use of RA as aggregate replacement in producing new concrete has been experimentally proven to have adverse effects on the mechanical and physical properties of the concrete, it can be ameliorated using mineral additives as a partial cement replacement, such as the incorporation of silica fume and fly ash (FA) [16,17]. Weakening of the concrete qualities from RA occurs mainly due to heterogeneity and the presence of impurities, pores, and old mortar in the RA, which will have a lower density and higher absorption [17,18]. Dilbas et al. [19], who studied the effects of using silica fume with RA, concluded that compressive strength of 5% and 10% silica fume increases by 3.23% and 12.9% respectively, compared to RAC with 0% silica fume. The noticeable increase in compressive strength of the concrete with silica fume replacement is attributed to the filler effect along with the pozzolanic effect [20]. Golewski [21] evaluated the effects of incorporating FA to produce green concrete. The optimum average 28-day compressive strength obtained was 48.96 MPa at 20% FA replacement. The author also concludes that using 20 or 30% FA drastically reduces the compressive strength at an early age.

High strength concrete (HSC) is a topic that has been gaining interest over the years [22]. The applications of HSC increased within the last few decades, in which HSC was used in high rise buildings. Kou and Poon [23] evaluated the mechanical properties of RA made from parent concrete (PC) that had the 28 days compressive strength ranging between 30–100 MPa. At 28 days, the concrete made from PC of 80 and 100 MPa had compressive strengths exceeding 65 MPa, which is slightly larger than natural aggregate concrete (NAC). At 90 days, the compressive strengths for both mixes reached 75 MPa. The 28 days splitting tensile strengths for all mixes were less than the NAC; however, they all exceeded NAC after 90 days. The largest compressive strength obtained by Tu et al. [24] was 42 MPa after 91 days at w/b of 0.32. The results dictate that the compressive strength of both natural and recycled concrete decreases with the increase in w/b. They also emphasized that the impurities, as well as the residual mortar, are the main reasons that RA has inferior soundness, absorption capacity, and specific gravity than natural aggregate.

Zaetang et al. [11] evaluated the mechanical properties of previous recycled block aggregate (RBA) and previous recycled coarse aggregate (RCA). The results of the compressive strength for RBA and RCA were 17 MPa and 15 MPa, respectively, which were greater than the conventional concrete (CC) at 13.4 MPa. Both types of recycled concrete did not significantly influence the splitting tensile and flexural strength. Xuan et al. [9] reported that using 100% carbonated RA improved the bulk electric conductivity, chloride ion permeability, and gas permeability by 15.1%, 36.4%, and 42.4%, respectively. However, the chloride ion permeability value was 1.5 times larger than the reference concrete. Kou and Poon [23] suggested that the poor durability of recycled concrete could be compensated using FA. They also stated that replacing cement with FA is more economical and environmentally friendly. Golewski [25] showed that concrete with 20% FA substitution is characterized as having high durability and low permeability. Seara-Paz et al. [10] studied the work performance of reinforced concrete beams made with 0, 20, 50, and 100% RCA. They reported that the cracking moment is inversely proportional to the replacement ratio. Sim and Park [26] reported that for 100% coarse aggregate replacement, the total charges passed are 2100, 950, and 350 coulombs for 0, 15, and 30% FA, respectively. The authors subsequently concluded that FA greatly reduces the chloride penetration. Golewski [27] reported that for matured concrete, the microcracks in the Interfacial Transition Zone (ITZ) are minimal when 20% FA is used.

The purpose of this paper was to design, produce, and evaluate high performance concrete (HPC) made with RA as a partial coarse aggregate replacement. The RA replacement levels were 20, 50, and 80%, denoted as RA20, RA50, and RA80, respectively. The cementitious materials used were micro silica (MS) and FA. The fresh and hardened properties measured in this scope include slump, air content, density, compressive strength, tensile strength, modulus of elasticity, and chloride ion penetration.

2. Materials and Methods

The scope of this research was to evaluate the fresh, mechanical, and permeability properties of concrete made with RA and compare the results with conventional high strength concrete (CHSC). The three mixes conducted in this experimental program, which entailed different RA replacements of 20%, 50%, and 80%, denoted in this paper as RA20, RA50, and RA80, respectively, were compared to the properties of CHSC. The mixes were designed in accordance to the modified version of the ACI 211-1 design method. Cementitious materials were also used to enhance the properties of the concrete. All mixes were unique in that they had different RA replacement levels, as well as different cementitious materials and quantities used, while maintaining a constant w/b ratio of 0.31. The fresh properties that were evaluated include: air content, fresh density, and slump flow, in accordance to ASTM C231-10 [28], ASTM C172-99, and ASTM C143 [29], respectively. The hardened properties assessed in this paper include compressive strength, tensile strength, modulus of elasticity (E), and chloride permeability, in accordance to ASTM C109 [30], ASTM C-496 [31], ASTM C469-10 [31], and ASTM C1202 [32], respectively.

A total of thirty-six cubes with dimensions of 150 × 150 × 150 mm were tested for compressive strength. Eight cylinders with dimensions of 150 × 300 mm were tested, in which four were used for the split tensile strength, and four for E. Twelve specimens were also tested for rapid chloride permeability test (RCPT), with each mix consisting of three samples. The samples were demolded after 24 h from the time of casting and later underwent water curing within a controlled laboratory environment with a surrounding temperature of 20 ± 5 °C.

Materials

The materials used in this research include RCA, normal coarse aggregate, Ordinary Portland Cement (OPC), MS, FA, water, crushed fine aggregate, and Glenium Sky 502 superplasticizer. The RCA used in this research was obtained locally from the Bee'ah organization in the United Arab Emirates. Two aggregate groups of the same type were blended and used in this experiment. The groups include 5–10 mm and 10–20 mm aggregate. Several physical properties of the aggregate were determined including: Sieve analysis, aggregate crushing value, specific gravity, water absorption, Los Angeles abrasion, in accordance to ASTM C136-01 [33], ASTM C131, ASTM D75-97, ASTM C702-98, and ASTM C131-96, respectively. Table 1 summarizes the RA properties for the two samples of aggregate with sizes of 5–10 mm and 10–20 mm. Figure 1 depicts the particle size distribution of the RA. The graph shows that the aggregate was well-graded and well-distributed. All mixes included OPC with a specific gravity of 3.14 and MS with a specific gravity of 2.2. Furthermore, the superplasticizer had a specific gravity is 1.115 and a solid content of 46%. Finally, the FA specific gravity was found to be 2.8.

Table 1. Properties of recycled aggregate (RA).

Recycled Aggregate	Sample #1(10–20) mm	Sample #2 (5–10) mm
Aggregate Crushing Value	18.88	22.2
Bulk Specific Gravity	2.48	2.56
Apparent Specific Gravity	2.78	2.77
Water Absorption	4.2%	2.8%
Percentage Loss (L.A. Abrasion Value)	70.8	77.2

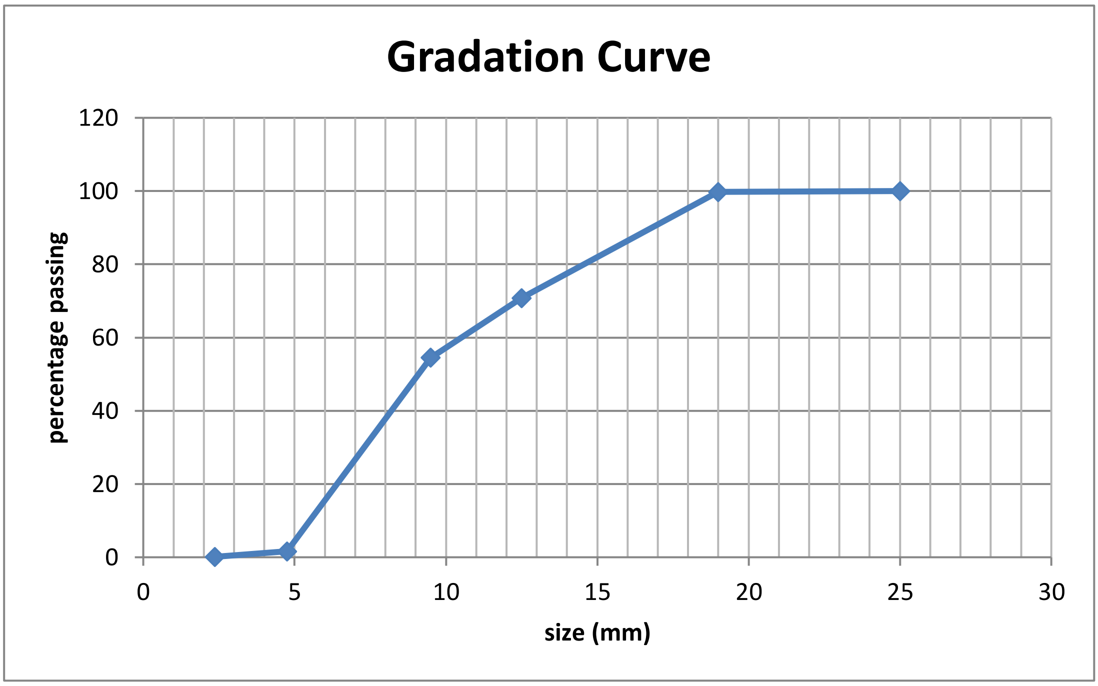

Figure 1. Aggregate gradation.

The mix proportions used in this experiment are displayed in Table 2. The weight of the RA changed according to the mix and increased gradually from CHSC to RA80 (80% RA). The w/b ratio was kept constant at 0.31 for all mixes. MS and FA were used in all recycled concrete mixes, where MS was kept constant at 10%. RA20 used similar MS and FA weight, with each being 10% of the total binders used. RA50 used 25% FA, whereas RA80 used 40% FA. Superplasticizer was fixed at 1.5% by volume for all the mixes. The objective of the trials was to optimize the concrete's fresh and hardened properties with the aid of pozzolanic materials.

Table 2. Mixtures proportions. CHSC = conventional high strength concrete; w/b = water-to-binder.

Mixtures	CHSC	RA20	RA50	RA80
Cement (kg)	432	381.3	312	240
Fly ash (kg)	-	48	120	191
Micro silica (kg)	48	48	48	48
Water (L)	148	149	153	158
w/b	0.31	0.31	0.31	0.31
Recycled coarse aggregate (kg)	-	217	542	861
Normal coarse aggregate (kg)	1089	870	542	215
Fine aggregate (crushed sand) (kg)	685	667	636	571
Superplasticizer (L/m^3)	21.85	21.85	21.85	21.85

3. Results and Discussions

3.1. Fresh Properties

The fresh concrete properties are displayed in Table 3. The air content values ranged from 1.3 to 1.7% with the lower limit for the CHSC, and it increased with the use of RA. A possible explanation for the increase in the air content would be the presence of pores in the aggregate, as well as their irregular shapes. The density of each recycled concrete mix was larger than CHSC, except for RA80. This could be attributed to the filling of the pores by the cementitious material and calcium silicate hydrate (CSH) gel from the hydrated cement. In the case of RA80, the excessive pores were not accessible for the cementitious material and the gel to occupy, thus, leading to vacant pores in the concrete.

Table 3. Fresh concrete properties.

	CHSC	RA20	RA50	RA80
Air Content (%)	1.3%	1.7%	1.6%	1.6%
Density of Fresh Concrete (kg/m^3)	2356	2408.7	2389.9	2259.5
Slump (mm)	53.5	54.5	55	53.5

All RA mixes had a higher slump than CHSC, except for RA80. The increase in slump was mainly due to high initial free water content. The free water was a result of the high-water absorption capacity of RA. The slumps of all recycled HPC mixes had an average of 54.3 mm, which was an indication that all the mixes had very good flow ability. The slump slightly increased between CHSC and RA50, where it was maximized, but then dropped to 53.5 mm for RA80, which is similar to CHSC.

3.2. Compressive Strength

The results for the compressive strength of the concrete specimen at seven, 28, and 56 days are illustrated in Figure 2. The crushed cubes at seven and 28 days are shown in Figures 3 and 4, respectively. The results displayed are averages of three cubes for each of the respective mix. At seven days, the compressive strength for RA20, RA50, and RA80 were found to be 68, 75, and 66% of the compressive strength of CHSC. The 28-day compressive strength for RA20, RA50, and RA80 were obtained to be 71, 76, and 73%, respectively, of CHSC. At 56 days, the compressive strength for RA20, RA50, and RA80 were obtained to be 74, 84, and 85%, respectively, of CHSC. The decrease of the compressive strength occurred due to the presence of old cement dust on the RA, which contributed to the debilitation of the aggregate. However, the weakening of the concrete mechanical properties could be compensated with the utilization of cementitious material. The cementitious materials contributed to the enhancement of the properties by the pozzolanic reaction. The reaction occurred between the calcium hydroxide of the hydrated cement and the silicates to produce CSH gel [22,34].

The rate of strength gain for the RA specimen increased with the increase of the curing period, thus reducing the strength loss for all specimens in comparison to the CHSC. The increase in the rate of strength gain was mainly due to the delayed reaction of the FA, which is known to develop long term strength. At seven days, the average compressive strength of RA80 (40% FA) was less than RA20 (15% FA) and RA50 (25% FA). However, it was manifested later to possess a higher compressive strength than both averages. All RA curves showed a continuous increase in the compressive strength, whereas the slope of the CHSC began to stabilize horizontally. Similar to other studies, the compressive strength of the specimen increased with an increase in the curing period [35]. The results of the compressive strengths in this experiment were comparable to the CC obtained from earlier studies [14,34]. Gales et al. [36] achieved concrete compressive strength exceeding 45 MPa at full replacement, however, the strength decreased significantly when the specimens were exposed to high temperatures. For long term performance, Kou and Poon [37] achieved a maximum compressive strength of 69 MPa at high RA replacement and 35% FA. The compressive strength of RAC reduced with the increase of RA. At 50% RA and 25% RA, the 28-day compressive strength was obtained to be 48.1 MPa [36]. Zaetang et al. [11] reported that the optimum replacement of previous RCA was at 40%. Sim and Park [26] achieved 28-day compressive strengths of 52 MPa and 50 MPa for 0% and 15% FA, respectively, with RCA without the incorporation of recycled fine aggregate. The authors concluded that regardless of the curing condition and cementitious material, the 28-day compressive strengths of the RAC exceeded 40 MPa. The compressive strengths exceeded 50 MPa at 56 days in any cementitious material replacement without recycled fine aggregate [12]. Aslani et al. [38] assessed the mechanical effects of incorporating RA into self-compacting concrete with replacements from 0–40% at 10% increment. Their results showed a slight gradual decrease in the compressive strength where the control concrete achieved a 28-day compressive strength of 50.39 MPa. On the other hand, the lowest 28-day compressive strength achieved was 43.82 MPa at 40% replacement. Kou and Poon [39] satisfied the requirements of producing HPC with 28-day compressive strength exceeding 65 MPa with old HPC as RCA.

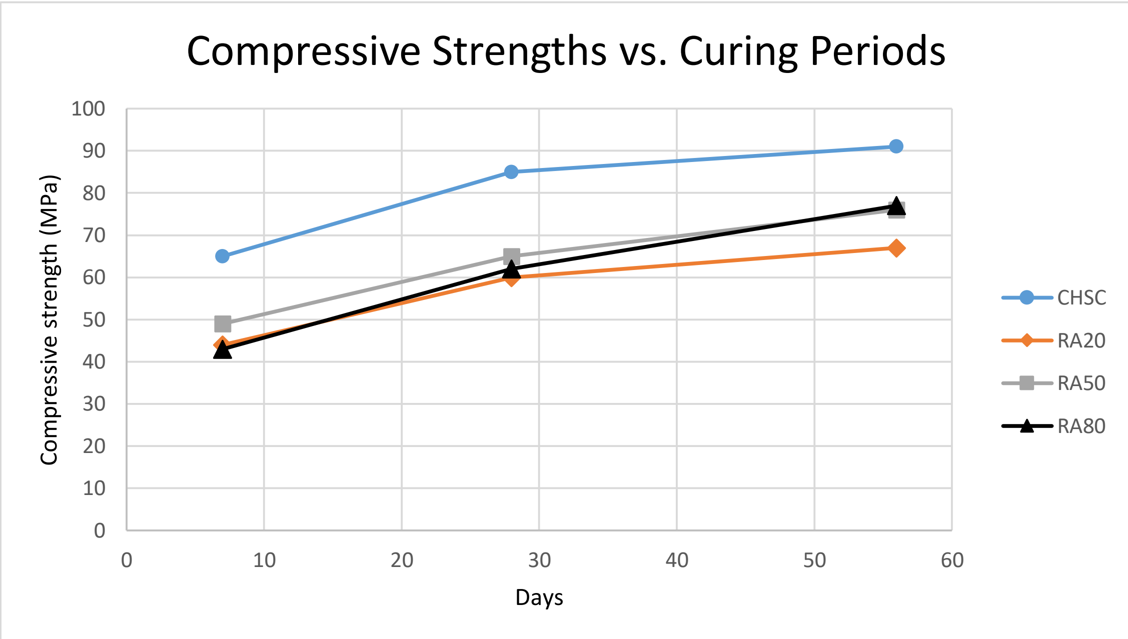

Figure 2. Compressive strength.

Figure 3. Concrete failure shape after seven days for all specimens.

Figure 4. Concrete failure shape after 56 days for all specimens.

3.3. Concrete Tensile Strength

The crushed speciemens are shown in Figure 5 and the results of the splitting tensile strength at 28 days of the 150 × 300 mm cylinders are shown in Figure 6. The splitting tensile strength of all RA concrete were lower than that of CHSC. The tensile strength for RA20, RA50, and RA80 were found to be 74, 90, and 73% of the tensile strength of CHSC. Similar to the compressive strength, the use of FA and MS were not sufficient to fully compensate the adverse effects of using RA on the mechanical properties of concrete. The use of 10% MS and 25% FA at 50% RA replacement showed a reduction in the tensile strength. Kou and Poon [37] investigated the tensile properties of using RA, FA, and different ratios. The results obtained of the 28-day tensile strength suggested that regardless of the RA and FA substitutions, the tensile strength would experience a reduction in comparison to the normal weight concrete. Mas et al. [40] also concluded that the splitting tensile strength of concrete made with RA would decrease in comparison to the normal weight concrete for concrete with targeted compressive strength above 60 MPa. Lee and Choi [18] came to the conclusion that the tensile strength decreases as the replacement of RA increases. The ratio of the splitting tensile strength to the compressive strength of the CC, RA20, RA50, and RA80 were found to be 4.67%, 4.86%, 5.46%, and 4.70%, respectively, which implies that the relation between both parameters of RA and mineral additives for each mix is closer to that of the CC. The results of Çakır [41] dictate that the tensile strength of concrete with 10% MS are 86, 63, 83, and 94% for 25, 50, 75, and 100% RAC, respectively, with respect to normal concrete. Binici et al. [42] reported that the 28-day splitting tensile strength of recycled concrete made from marble and granite increases by 57 and 52%, respectively.

Figure 5. Crushed samples with different types of aggregates.

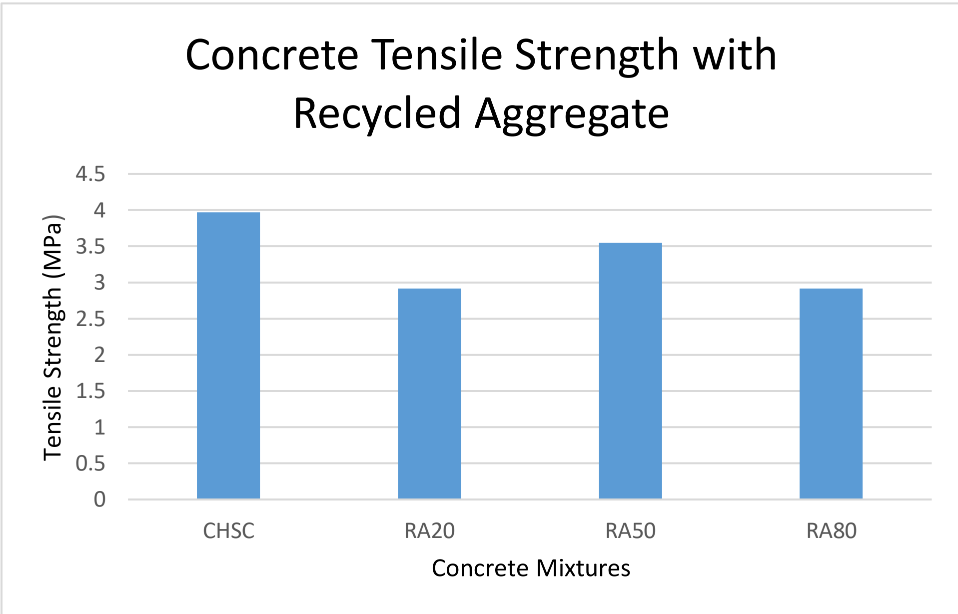

Figure 6. Concrete tensile strength.

3.4. Modulus of Elasticity

The modulus of elasticity (E) test showed the stress to strain ratio, as well as the lateral to longitudinal strain of hardened concrete. The test was conducted in accordance with ASTM C469 and the results at 28 days are displayed in Figure 7. It was clearly shown that the CHSC had the highest result, followed by the RA20 and RA80. The modulus of E of RA20, RA50, and RA80 were obtained to be 69, 50, and 56%, respectively, of the modulus of E of CHSC. Rahal [43] stated that the E of RAC was less than normal weight concrete for similar targeted strength. The author stated that the trend of E for RAC did not follow any steady pattern regardless of the targeted strength [41]. Dilbas et al. [19] concurred the previous conclusion with experimental analysis at different RA replacement ratios. Zhou and Chen [44] experimented on two types of RACs at various replacement levels. For both RACs, the modulus of E decreased with an increase in the replacement level [42]. The decrease in E with an increase in RA was due to the weak properties of RA, such as high porosity of old mortar and cracks [45]. Gales et al. [36] reported that the E of recycled concrete did not exhibit a stable trend where the modulus of E decreased at 30% RAC and increased again at pure RAC. Limbachiya et al. [1] reported that E increased with the increase of targeted strength and further increases were noticed with the incorporation of MS at all strengths. The authors stated that the E was dependent on the aggregate bulk. Generally, E experienced a gradual decrease with the increase of RA, where the lowest value of E was observed at 100% RA replacement for the lowest targeted strength with MS [1]. Binici et al. [42] achieved the values of E to range between 33.6–36.1 GPa, which were comparable with the results of this experiment at high RA ratios. Kou and Poon [37] concluded that E depended vastly on the strength of the PC. The 28- and 90-day E decreased with respect to NA, where E for 90 days was higher than that of 28 days. The range of 28-day E for the HPC mixes was between 31–36 MPa, which was compatible with the results of this experiment. Finally, E values rose with increased strength of the PC [36].

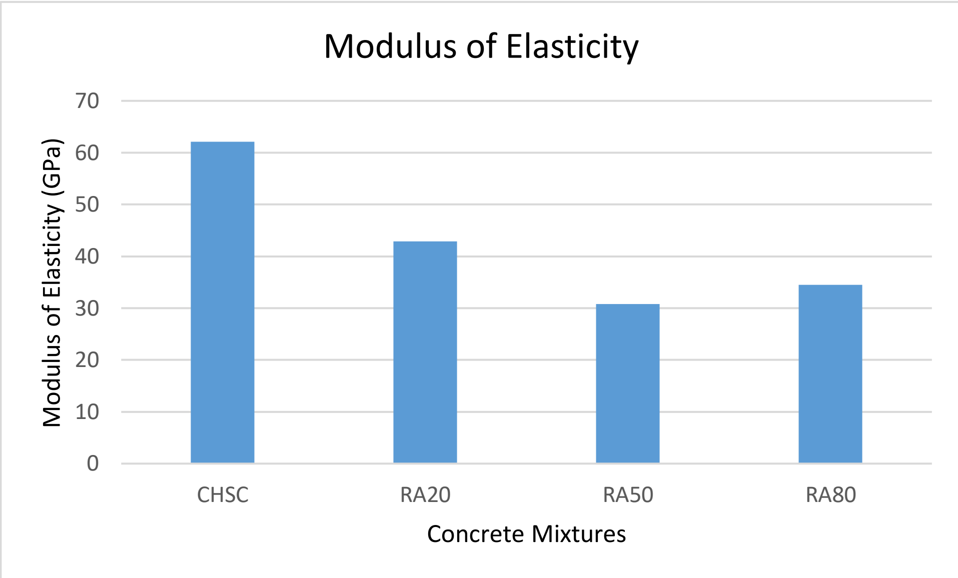

Figure 7. Modulus of elasticity.

3.5. Comparison of the Modulus of Elasticity with Other Codes and Papers

The American Concrete Institute (ACI) [46] and the Korean Concrete Institute (KCI) [47] are two common codes that are reliable for the construction industry. The modulus of E is dependent on the concrete density (ρ) and the compressive strength ($f'c$). E indirectly depends on aggregate type because the properties of the aggregates are imbedded in ρ and $f'c$. Several codes and papers introduce equations that predict the E of concrete. The ACI and the KCI propose Equation (1) and Equation (2), respectively.

$$\mathrm{E} = \rho^{1.5} 0.043 \sqrt{f'c}, \quad (1)$$

$$\mathrm{E} = \rho^{1.5} 0.077 \sqrt[3]{f'c}, \quad (2)$$

where ρ is the concrete density ($\mathrm{kg/m^3}$) and $f'c$ (MPa) is the concrete compressive strength. The density range of concrete is restricted between 1440 to 2560 $\mathrm{kg/m^3}$. Hossain et al. [48] proposed an equation for E using the same parameters, which is given as Equation (3):

$$\mathrm{E} = 30 \times 10^{-6} \rho^{1.5} \sqrt{f'c}. \quad (3)$$

Comparison of the modulus of E values with the predicted equations is illustrated in Figure 8, in which all results are represented as GPa. All the proposed equations follow a similar pattern and are relatively close. However, all the equations highly underestimate E for the concrete without any

RA (CHSC), with the ACI equation being the closest. The actual E gradually decreased with RA replacement until it reached RA50. All equations accurately predicted E for low replacement (RA20). However, ACI and KCI overestimated E at RA50. Moreover, E increased at RA80 where the exact value fell closely between the ACI and KCI equation. The equation proposed by Hossain et al. [48] was conservative for all the cases. ACI and KCI accurately predicted the modulus of E at various RAs, but it is recommended to modify the equations with a safety factor to accommodate uncertainties. It also showed that CHSC was higher than the values predicted, according to the equations of ACI, KCI, and Hossain et al. [46], by 43.3%, 60.4%, and 96.3%, respectively. The predicted equations were applicable for CHSC but needed to be modified for RA concrete.

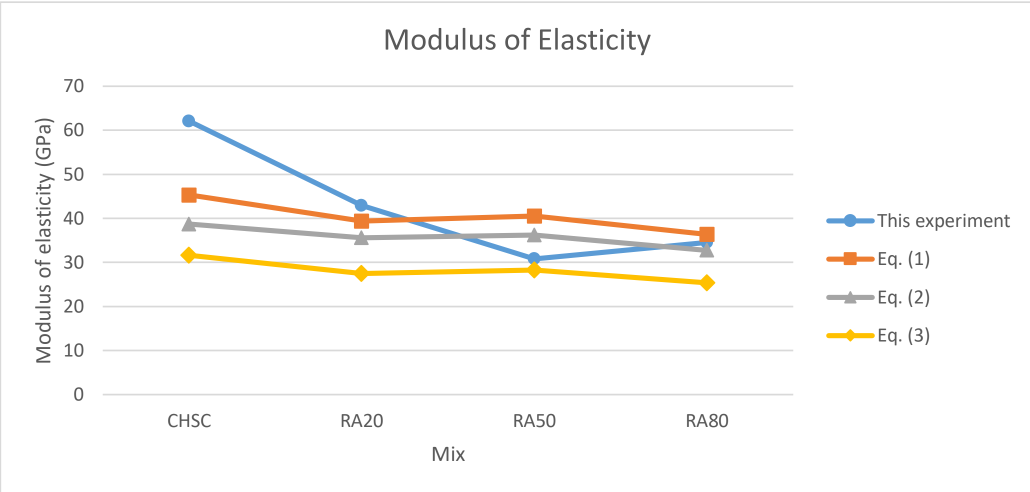

Figure 8. Comparison between the actual and predicted values of the modulus of elasticity.

3.6. Rapid Chloride Permeability Test (RCPT)

The electrical current transitory through the specimen would be restrained in milliamps by the RCPT device. The area under the curve of milliamps versus time would be used to develop the total charges. Moreover, the values attained were then compared to the ASTM C1202. The resistance to chloride penetration of all mixes was measured after 28 days after casting. Figure 9 illustrates the 28-day chloride ion penetration on the specimen. It is evident that the total charges passed decreased significantly in all mixes involving RA, with respect to the CHSC. The main contribution did not come from the RA, but the cementitious material used. The microstructure of the hydrated cement was greatly influenced by the pozzolanic reactions that resulted in the formation of CSH gel that was caused by the reaction of calcium hydroxide with the silicates from the pozzolans [20,49]. The CSH gel and the small particles size of the pozzolans filled the capillary pores and hindered the passage of the ions [24]. Therefore, the RA mixes were more durable than the CHSC. Ann et al. [50] confirmed the benefits of pozzolanic materials to reduce chloride penetration. Villagrán-Zaccardi et al. [51] mentioned that the contributing factors are the w/b ratio, type, and quantity of the cementitious material. Binici et al. [42] reported that the depth of chloride penetration decreases dramatically when RA are used instead of normal aggregate. The reduction in the depth were observed to be 71 and 63% [44]. Kou and Poon [23] reported that the chloride penetration resistance decreases as RA replacement increases. However, the use of FA adequately improved the resistance. The largest chloride penetration resistance observed was at 20% RA (lowest RA replacement) and 35% FA (largest FA resistance) at w/b ratio of 0.42 [23]. The fine particle size of cementitious materials also densified the pore structure of the concrete, enhancing the concrete's characteristics, such as increasing its compatibility and lowering its segregation [52]. Leng et al. [53] described four reasons on how the cementitious material could improve chloride penetration resistance: In that they improve the pore size distribution of the concrete; the presence of CSH gel absorbs chloride ions and blocks the diffusing path; the number of total ions, such as Ca^{2+} and Si^{4+}, that have low diffusing abilities are more present in pozzolans than OPC; and in the presence of C3A in the pozzolans, which can absorb more chloride ions. Evangelista and Brito [54] suggested that substitution up to 30% recycled fine aggregate is feasible for durability performance. Otsuki et al. [55] reported that the chloride penetration resistance increased with a decrease in the w/b ratio. For the same w/b ratio, the penetration of RAC was slightly inferior to NAC [53]. Sim and Park [26] reported that concrete becomes denser as the curing period increases. Therefore, the age of concrete is a major factor in determining the chloride penetration resistance, regardless of the amount of cementitious material. Final remarks by the authors state that RAC can achieve adequate chloride penetration resistance performance. The use of cementitious material can also aid in controlling the chloride penetration [26].

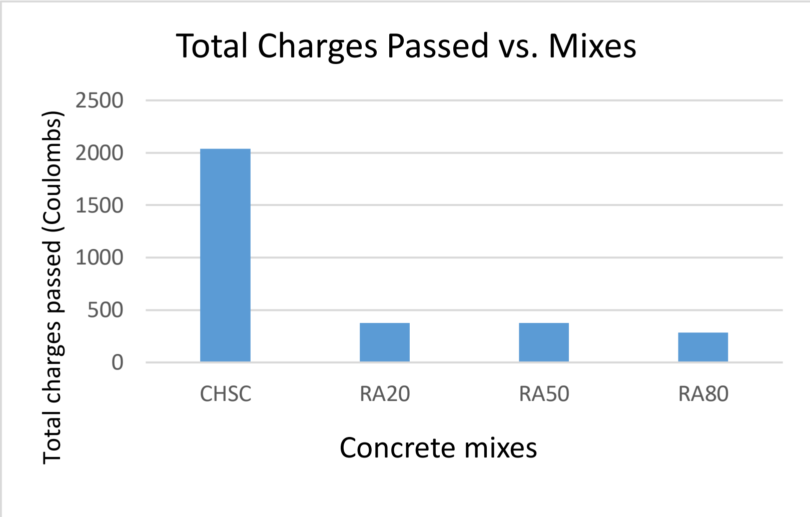

Figure 9. Rapid chloride penetration test (RCPT) results.

4. Conclusions

The aim of this experiment was to optimize the RAC properties using pozzolanic materials at different RA replacement levels. As such, this research has concluded the following:

- RAC is viable solution to reduce waste materials.
- Concrete made with 80% RA showed a high compressive strength of 60 MPa at 28 days and 77 MPa at 56 days.
- The workability of concrete made with RAs can be similar to CHSC.
- The pozzolans were highly effective in resisting the chloride ions. It reduced the permeability of the concrete with RA.

Author Contributions: Engineers F.S., H.A.A. and I.A. started the design of recylcled aggregate concrete mixture using waste concrete. They carried out several mixes in the lab and evaluated the fresh and hardened concrete properties. The work was supervised by A.T.

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Conflicts of Interest: The authors declare no conflict of interest.

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