

# Analysis of Durability in Self Compacting Concrete with Recycled Concrete Aggregates

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**Abstract** Self-consolidating concrete (SCC), which is also called self-compacting concrete, is a new technology that was made in Japan in the 1980s. Since then, the company's market share has grown fast due to the better quality of the concrete and the upgraded working environment. SCC is a type of concrete that flows easily, doesn't separate, and doesn't need mechanical consolidation to spread, fill the formwork, and cover the reinforcement. SCC can be compacted under its own weight because it flows easily. This lets it be used in difficult construction situations or sections with dense reinforcement. SCC can greatly reduce the amount of time it takes to place large sections of concrete by getting rid of the vibration process. This, in turn, helps reduce noise- and hearing-related injuries on the job site. SCC must be meticulously designed in order to achieve high flow ability and permeability while preserving sufficient stability to resist segregation. This article provides a thorough analysis of the benefits of compacting both fine and coarse recycled concrete. To reduce environmental consequences, the construction sector is requesting more modern methods. A Recycled Aggregate based Self Compacting Concrete (RASCC) is a new technology currently used in construction industries. In the concrete industry, recycled aggregates have global environmental advantages over natural materials and trash disposal. In recent years, the advantages of using RASCC have been increased which leads to research publications. Applying this method made the construction project highly creative and important for the environment and economic benefits of each material. The trials have demonstrated that this is possible in the

development of both traditional and semi-modern structural elements as well as enormously complex and substantially reinforced parts that hinder the mechanisms of vibration and ultimately affect performance.

**Keywords** Self-compacting Concrete, Workability, High Density Concrete, Slump Flow, Segregation Resistance, Flow Ability, Passing Ability

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## 1. Introduction

The Self Compacting Concrete (SCC) is a form of concrete originally produced in Japan in 1980, and it has exceptional resistance to deterioration and segregation. When the structures are being strengthened in a congested area, this can move under their weight and possibly completely fill the structures. High flow ability, high resistance to segregation, self-competitiveness, no vibration and noiselessness are some attractive features of SCC [1]. With a limited period, the concrete rate of placement is fast. Nowadays SCC is more commonly used and it offers the same technical property and longevity just like Conventional Concrete (CC). Construction and Demolition Waste (C&DW) is the primary source of Recycled Aggregates (RA), which are recovered from mineral waste sources. RA usually performs less than conventional aggregates. The density of RA remains lower compared to conventional aggregates. To achieve the desired quality of concrete made from RA a right mixing design is required. Studies on the characteristics of RASCC

have been supported by several researchers [2-4].

A brief analysis of literature from early work is as follows: both the RAs were utilized for investigating the properties of SCC. A three-series SCC blend of the sand river has been replaced by a structure constructed completely of recycled coarse pebbles. In all concrete mixes, the cement content is consistent [5]. It investigated the possible usage of Recycled Coarse Aggregate (RCA) procured from crushed concrete for SCC with a focus on environmentally sensitive interest. For the three kinds of concrete mixes, the percentage of RCA replacement was 0%, 50%, and 100% respectively [6]. All concrete mixtures were equally consistent during the mixing. Various curing conditions were used to measure the strength properties of mixes made from coarse RAs of crushed concrete.

Aggregates make up roughly 75–80% of the materials used to make concrete. Natural resource depletion and increased atmospheric pollutant generation result from the making and usage of environmental assets, that is the utilization of materials from environment for cement, recycling old concrete and concrete from damaged buildings is consequently crucial for the creation of aggregates [7]. The findings demonstrate that altering the water-cement ratio, altering the changing the RCAs' grain size and RCAs' Maximum Size (MSA), taking into account the strength of the parent concrete, and utilizing minerals and chemicals can significantly increase Compressive Strength (CS). Measuring the pulse velocity in concrete is among the most popular non-destructive techniques that are affordable and simple to use to assess the quality of concrete. This technique can be used to identify interior fractures and other faults in concrete and also the variations caused by freezing and thawing and the harsh chemical environment [8]. The concrete test specimens and in-place material properties can also be assessed using the Ultrasonic Pulse Velocity (UPV) method. The UPV approach is unquestionably non-destructive because it uses mechanical waves, which prevent any harm to the concrete component under test [9-11]. Repeated testing of a test specimen at the same site allows for the monitoring of concrete that is concrete test specimens and in-place material properties. One way to judge the durability of concrete with respect to corrosion and the entry of damaging elements is to test its concrete's ions' resistance is actually measured by electrical resistance, which is another name for it. By doing this, long lasting of cement can be estimated against chloride ion penetration [12]. Several factors cause porosity in RCAs and concrete made with them to absorb more water; however,  $\text{Cl}^+$  penetration can be minimized by adding minerals such as Metakaolin

(MK), Fly Ash (FA), Silica Fume (SF) and Ground-Granulated Blast Furnace Slag (GGBS).

### 1.1. Significance of Research

The use of CC and SCCs has been rising dramatically in various research and development studies. Although the substantial research has been conducted on the impact of RCAs on the durability of CC, their implications on the performance of SCC remain unknown. Consequently, it is essential to explore the duration of SCCs, specifically RCAs. This experiment investigated the unique impacts of recycled coarse and fine aggregates on the mechanical characteristics, freshness, and durability of SCC. In addition, the relevance of the parameters that influence the durability qualities of RCA-based concrete is investigated. The goals are to understand how SCC made with RCAs respond to harmful attacking agents, particularly chloride ions, and to minimize the consumption of natural resources. Numerous experiments, including those for the volume of permeable gaps, compressive and tensile strengths, water permeability, UPV, the rapid chloride penetration test, and electrical characteristics, were done in this respect. SCCs comprising recycled fine and coarse aggregates are researched and compared with SCCs containing just natural aggregates to determine the effect of varying RCA on concrete durability. Evaluation techniques for the Electrical Resistivity (ER) of concrete can be used to evaluate how well concrete resists corrosion and Chloride Ion ( $\text{Cl}^+$ ) penetration, and by total charge passed,  $\text{Cl}^+$  penetration resistance. Consequently, Rapid Chloride Permeability Test (RCPT) and bulk ER tests based on were considered.

## 2. Materials and Methods

### 2.1. Source Materials

For this investigation, The Hegmatan cement mill provided Type II Portland cement. The chemical, mechanical and physical specifications are shown in table 1. The sources of the RCAs employed and the features of waste aggregates are presented in table 2. Powder ingredients included limestone with a certain gravity of  $2.58 \text{ gr/cm}^3$ . In the plant, all gravels have collapsed [on practically all sides], and RCAs have been crashed in the lab. A portion of the RCAs were hand-crushed with a hammer to generate finely recycled concretes after being first crushed by a tiny rock crushing machine.

**Table 1.** Chemical, Mechanical, and Physical Properties of Cement

Chemical Properties	%
Silicon dioxide - SiO <sub>2</sub>	21.26
Calcium oxide - CaO	62.96
Ferric oxide - Fe <sub>2</sub> O <sub>3</sub>	4.04
Aluminium oxide - Al <sub>2</sub> O <sub>3</sub>	4.94
Magnesium oxide - MgO	1.54
Sodium oxide - Na <sub>2</sub> O	0.5
Potassium oxide - K <sub>2</sub> O	0.62
Sulfur trioxide - SO <sub>3</sub>	2.24
Tricalcium aluminate - C <sub>3</sub> A	6.30
Loss on Ignition - LOI	2.11
Physical Properties	
Specific gravity	3-3.0
Specific surface (cm <sup>2</sup> /g)	2909
Setting Time (min)	Initial – 153
	Final -194
Mechanical Properties	
Mortar (Days)	CS (MPa)
3	20.2
7	28.1
28	40.2

Gradation curves reveal that whereas fine RCAs and fine natural aggregates have identical fineness modules, RCAs have a 7-fold higher water absorption rate. Water absorption in RCAs increased as a result of adhered mortars. Additionally, a simple comparison of the particular gravities of aggregates reveals that RCAs have low specific gravity than natural aggregates [13]. Contrary to this, as shown in Figure 1, coarse natural aggregates are larger than the coarse RCAs. In accordance with EFNARC specifications, to achieve the required workability in the 850-550 mm range, polycarboxylate superplasticizer (SP) was utilized.

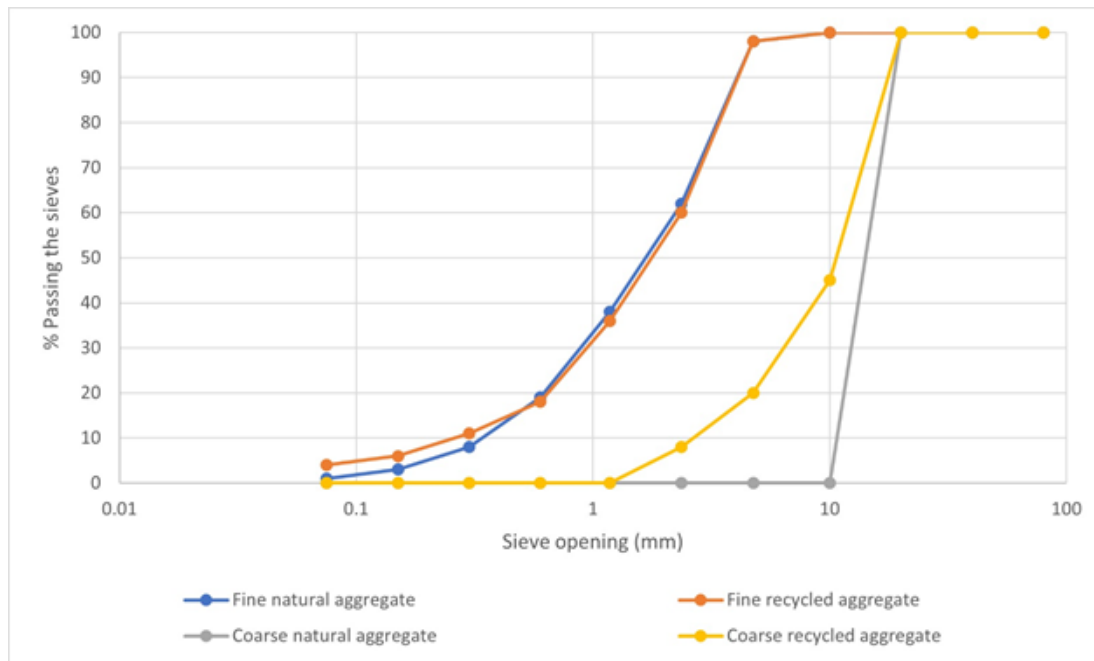
- After eliminating all contaminants including wood, plastics, asphalt, bricks etc., a RCA example (mi) is

prepared. Two hours are spent submerging the sample in water to nearly completely wet the mortar that is attached.

- After that 500 degrees are used to dry the sample in a muffle C 1826 for 2 hours. The sample is then submerged in ice water. The fast cooling after this heating creates stress and fissures in the mortar, which are easily repaired. In the saturated mortar, the heating produces water vapour.
- Following these procedures, some mortar typically remains adhered, therefore it must be removed with a hammer made of rubber or by scraping the exterior.
- The model is screened through a 4 mm filter to extract the coarse aggregate after all of the mortar has been removed (mf).

**Table 2.** Source of Waste Aggregates

Kind of Structure	Kind of Building	Sample Site	CS (MPa)
Concrete material	Housing	Rooftop 1	36
		Floor 1- Pillar	39.4
		Rooftop 2	40
		Floor 2 - Pillar	43
		Rooftop 3	44
		Rooftop 4	40
Concrete material	Housing	Floor 2- Pillar	41
		Rooftop 3	37.52
		Floor 3 - Pillar	38.50
		Rooftop 4	41
		Floor 4- Pillar	47
		Rooftop 5	44
Steel	Clinic	Rooftop 2- Block A	35
		Rooftop 2 - Block B	38
		Rooftop 5 - Block A	36
		Rooftop 5 - Block B	37



**Figure 1.** Gradation of Coarse and Fine Aggregates

## 2.2. Procedure and Design Mix

In this experiment, 12 mixtures of fine and coarse RCAs were made and compared to a reference mixture at 25%, 50%, 75%, and 100% replacement levels. The first sequence of the mixture used rough RCA, the second sequence used refined RCAs, and the third sequence combined the usage of fine and coarse RCAs. The usage of coarse and fine RCAs is denoted in the mixes by the letters C and f, respectively. Pre-numbered letters additionally indicate the volumetric recycling aggregates proportion [14]. Before mixing, RCAs were presoaked. The efficient method for separating impurities and obtaining RCA of a higher caliber presoaking is done. When mixing water, the RCA has absorbed some amount of water before usage has been considered and calculated carefully. Parameters for the blending strategies in a dry, Saturated Surface Dry (SSD) are well distinguished.

## 2.3. Test Methods

Newly mixed concrete of each type was put into cylinders and cubic molds. All samples were kept at 100% relative humidity for 24 hours prior to de-molding. The concrete samples were cured in water prior to testing. Three examples of each mixture were cast and allowed to cure for the duration of each test [15]. For each combination, three

test samples were utilized: a 100 mm cube sample aged 7 and 28 days for CS testing, a 100 mm cube sample aged 7 days for CS testing, and a 100 x 200 mm cylindrical sample aged 28 days for splitting tensile testing.

At age 28 days, the absorption of water test was carried out on 75 x 75 mm cylinder embodiment. Likewise, American Society for Testing and Materials (ASTM) C 642-13 in hardened concrete to measure the Permeable Voids (PV) was considered. Based on ASTM C597, the test for measuring pulse velocity was conducted, on a cubic sample of 100mm of aged 3, 7, 11, 14, 21, 25, and 28 days, cemented concrete. A tool that can measure 0.1 as a pulse velocity microsecond with a 54 kHz transducer frequency was utilised for this test. The apparatus was calibrated with a reference rod.

At ages 3, 7, 11, 14, 21, 25, and 28 days, the ER of a 100-mm cube of hardened concrete was measured. The test utilized Saturated Surface Dry (SSD) specimens. When specimens were sandwiched between two copper plates, the crossing of R was determined. Using eq. 1, ER is computed.

$$\rho = R \times A/L \quad (1)$$

Where A denotes the specimen area ( $m^2$ ), R denotes the electrical resistance ( $\Omega$ ), and L is the length of specimen (m) and  $\rho$  is the ER ( $\Omega, m$ ).

### 3. Results and Discussion

#### 3.1. Split Tensile and CS Results

According to the CS measurements, the first series' coarse RCA replacements caused a reduction at 7 and 28 age by its CS. At the age of 28, the CS has decreased by 32% after replacing 25%. The mix's maximum reduction at 28 days was 43% when 75% of it was replaced (fig 3). According to earlier research, the CS of SCC will decrease when the replacement of RCAs rises. The high is probably because of the RCAs' permeability and the insufficient concrete network adhering to the RCAs. Interfacial Transition Zone (ITZ), which has the lowest indentation modulus, is where the concrete is most vulnerable [16]. Contrarily, coarse RCAs are more compact than coarse natural, due to the particular exterior zone it increases the aggregates, which encourages the construction of many ITZs. The CS may suffer as a result.

By observing the second series the CS is decreased by 52% when it is replaced by 75% of fine RCA. With respect to the findings, when the fine RCA material rose, the compressing resistance of SSC mixtures reduced. RCAs

indicated that when the ratio of fine RCAs was 100%, utilizing RCAs reduced CS by 26% compared to reference concrete. A separate study found that fine RCAs decreased the compressive resistance of concrete when it was exposed to dry air and 100% relative humidity. Compared to previous recycled concrete mixes, the combination of coarse and fine RCAs increased constriction force, possibly due to the two RCAs' good consistency [17]. Some publications have reported that the reduction has not changed as a result of the replacement. Researchers have determined that RCA texture is the root of the problem, and that cement paste and RCA should be properly bonded. Figure 2 illustrates how the CS of mixes decreased in comparison to reference mixes. With 24% of the RCAs replaced, the Split Tensile Strength (STS) enlarged from 9% to 30% compared to the reference mix. The substitution of 50 to 100% coarse RCAs had no noticeable effect on the decrease in STS, but the substitution of 5 to 100% fine RCAs and both recycled fine and coarse aggregates increased STS. Several studies concluded that the replacement of RCAs had no significant consequence on the loss in STS.

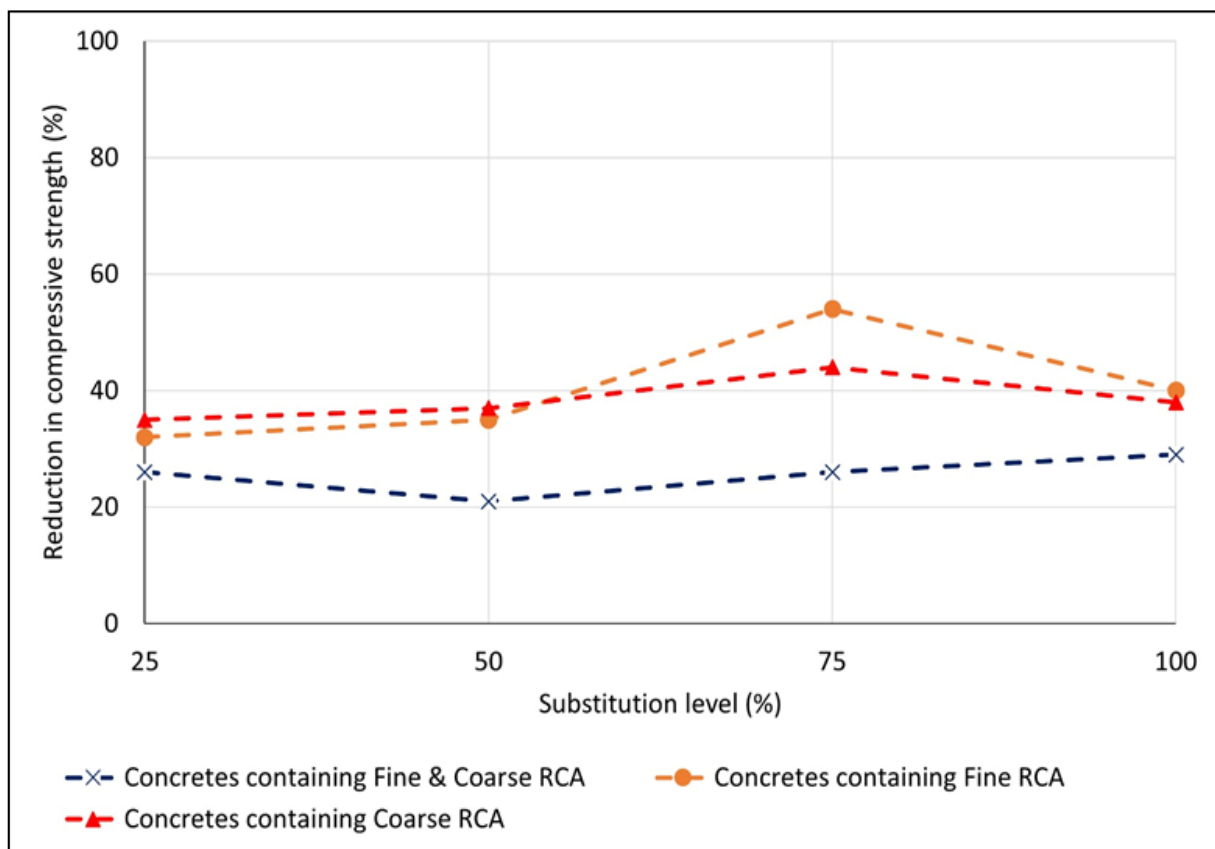


Figure 2. CS of mixes is lower compared to the reference

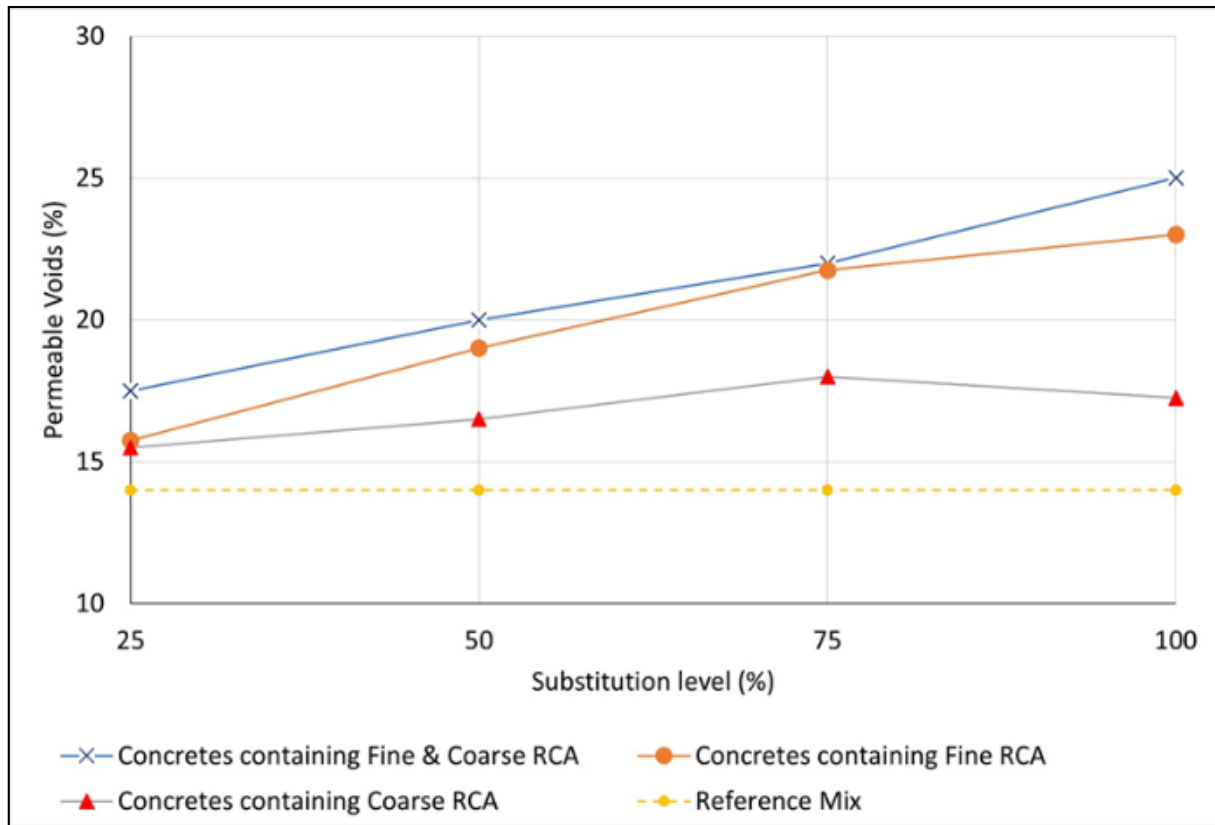


Figure 3. Permeable voids in hardened concrete at 28 days

### 3.2. Permeable Voids and Water Absorption

After the samples had dried completely in the oven, a test for absorption of water is regulated. The findings show that absorption of water increased as RCAs were replaced more frequently. The first phase of replacement with 25% of RCA improved the absorption of water by 6.4%. Water absorption improved by 14.6%, 64.6%, and 66.1% for 52%, 75%, and 100% replacements, respectively. The mixtures considerably absorbed more water in the second series. Water absorption improved by 41%, 72%, 155%, and 193 % when 25%, 50%, 75 % and 100% were substituted by fine RCA [18]. In the third sequence, the mixture of coarse and fine RCAs boosted water absorption. Water absorption rose by 65 to 171% when 25% to 100% of RCAs were replaced.

According to certain researches, the high water absorption of these aggregates and the RCAs with larger absorptive will significantly increase the absorption of water concrete. The absorption of water test findings also shows that changing the RCAs will increase concrete water absorption, and increasing RCAs would further increase concrete water absorption. Compared to concretes without fine RCA, concrete compositions containing fine RCA have a substantial effect on water absorption. In the S100f and S100Cf, substituting coarse RCAs with fine RCAs boosted water absorption by 87 and 109%, respectively. It demonstrates that fine RCAs have a higher SCC absorption

rate than coarse RCAs [20]. This is due to two factors: first, the proportion of fine RAs in SCCs is often larger than that of coarse RCAs, which increases the concrete's surface area and water absorption; and second, recycled fine aggregates absorb more water per unit volume than coarse RCAs. Figure 3 depicts permeable voids in cemented concrete after 28 days.

### 3.3. Ultrasonic Pulse Velocity

At 28 days, Series 1 pulse velocities varied from 4.417 to 4.629 km/s. Increasing the coarse RCA replacement has reduced the velocity of the pulse, but this effect is not significant. The pulse velocity decreased by 4.58% when RCA replacement went from 25 to 100%. Due to RCAs' low density, concrete made with this form of aggregate has a lower pulse velocity. A study demonstrates that when mortar adheres to RAs in SCCs, the porosity of the mortar reduces the velocity of the pulse. Although in the next round of mixtures, the quantity of fine RCA replacement increased, the difference in pulse velocity was incredibly modest. After 28 days, the variation in pulse rate between a 25% and 100% pulse rate replacements is only 5.48% [19]. In a different research, it was found that increasing the proportion of recycled fine aggregates from 25 to 100% at 90 days improved the performance of the system, and very slightly increased pulse velocity by 3.17%. According to the results, the time period between three and seven days

had the highest gradient in the graphs, and the greatest growth rate was observed in all mixtures at pulse velocities at young ages. The gradients considerably decreased after about 7 days.

According to this, the majority of cracks and holes in concrete are filled during the cement's hydration reaction for up to seven days. From seven to 28 days, however, the reaction rate is dramatically lowered, and as a result, the velocity of the pulse will be slowed. This behaviour of the concrete resembles CS behaviour quite a little. Additionally, as the pulse's speed depends on the concrete's density and boundary layer, the percentage of water to cement can be decreased while its specific gravity is increased. Given that the density of concrete varies so little over time, the variation in UPV will be quite minor. All mixes are compared to the reference, which demonstrates how RCAs will slow the pulse rate. In fact, the recycled concrete pulse takes longer to pass because of the absorptive in the binder that adheres to the RCA. The pulse velocity decreases when 25% and 50% RCAs are substituted yet the mix quality remains high. However, even if the number of RCA being replaced has increased by higher than 50 percent, the mixture standard has lowered only little and is still well for the remaining mixtures.

### 3.4. Electrical Resistivity

The ER test's findings revealed that, the reference concrete is being compared; the replacement of coarse RCA by 25% had no effect on the concrete's ER. However, in reference to the mixture with 25% coarse RCAs and the different mix, the ER dropped with an increase in replacement. Compared to S25C, ER is decreased by 10.8%, 18.6% and 18.8% when it is replaced by coarse RCAs by 50%, 75% and 100%. The concrete becomes more porous when RCAs are replaced more frequently,

which ultimately causes the decrease in ER. The ER will be decreased as the aggregate size decreases. The natural aggregates are larger in size compared to coarse. Additionally, the outcomes demonstrated that cement hydration persisted and the ER rose over time for all combinations. The ER was reduced by 8.8%, 21%, 39%, and 46%, respectively, by substituting 25%, 50%, 75%, and 100% of the RCAs. It is possible to conclude that recycled fine aggregates have greater permeability than RCAs and are therefore more effective at reducing ER. Comparing the water absorption test section results and accounting for the fact that the volume of the fine RCAs in SCC is much bigger than that of the coarse RCAs.

### 3.5. Rapid Chloride Penetration

Figure 4(a, b, c&d) depicts the results of the  $Cl^+$  penetration test conducted on 28-day-old animals. Results from the initial sequence demonstrate that the replacement of RCAs increased the time-current intensity's exterior under curve, indicating the total charge transmitted. It rose by 16.4% when coarse RCA was replaced by 25% coarse RCA. It was increased by 20.3%, 25.9%, and 17%, respectively, in place of 50%, 75%, and 100%. Porosity is what causes the total charge to rise, and since in RCAs the aggregate porosity rises as a result of the binder attaching to the aggregates, charge transmission will likewise rise. Another investigation revealed that as the charge transmission rose as coarse RCAs were increasingly replaced in FA-containing SCCs [20]. The total charge transmission increased by 9.3% to reach 43% by substituting 60% of mixtures with different water-cement ratios that contain grainy RCAs. In this investigation, the rise was also brought on by the increased porosity of the coarse RCAs. The surface under bent in Fig. 4b grew in the second batch after fine RCAs were replaced.

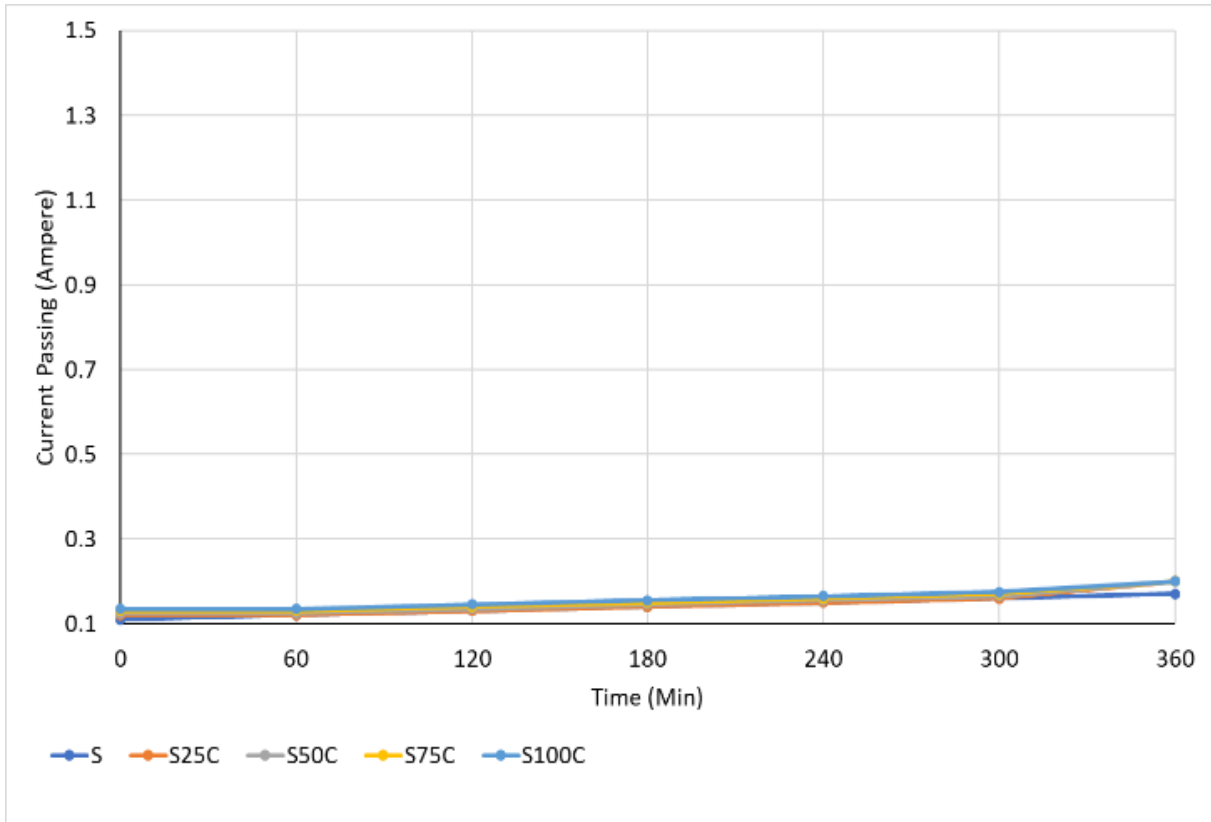


Figure 4a. The effect of chloride ion penetration in Ras, coarse RCA containing mixture

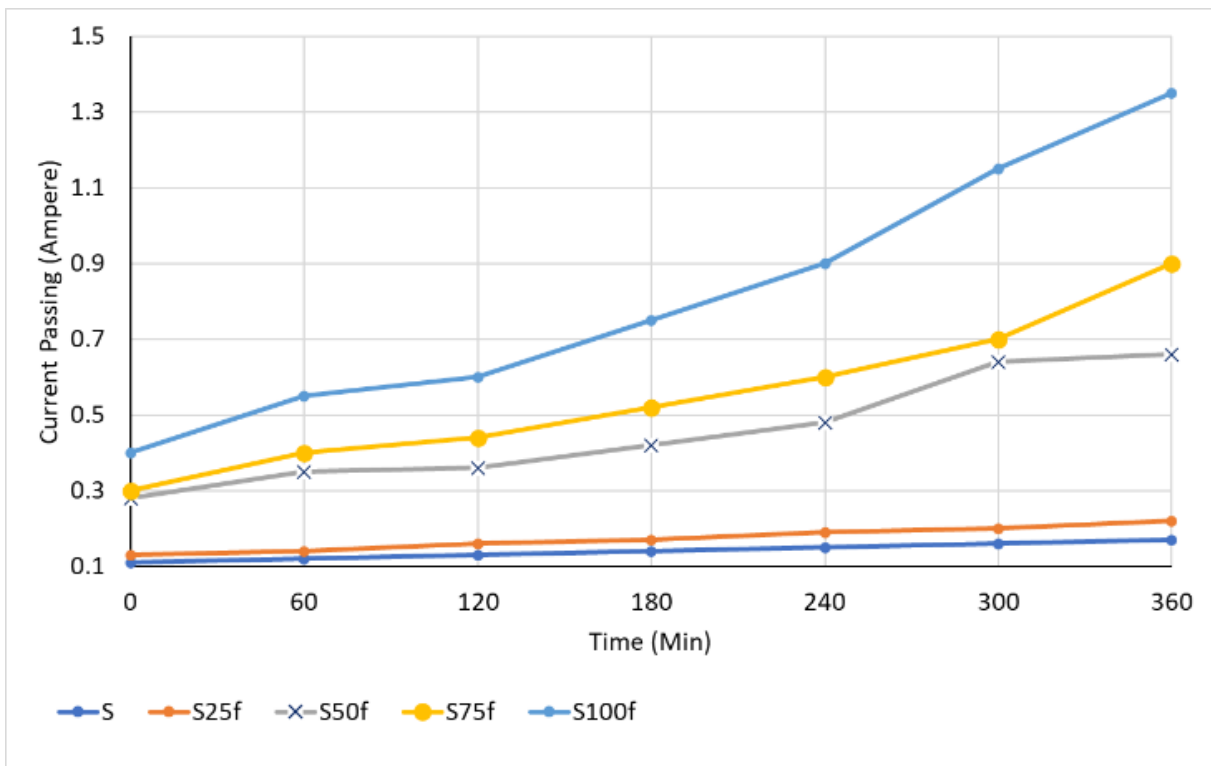


Figure 4b. The effect of chloride ion penetration in Ras, fine RCA containing mixture

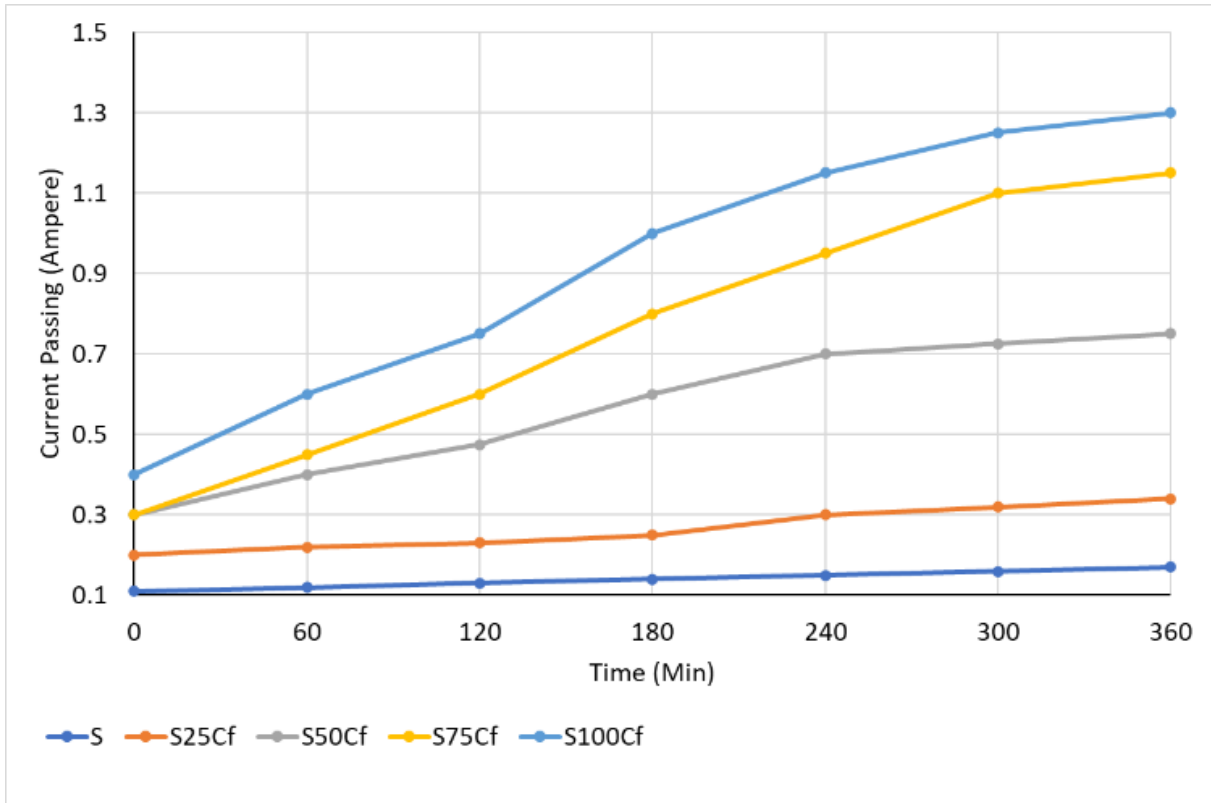


Figure 4c. The effect of chloride ion penetration in Ras, both coarse and fine RCA containing mixture

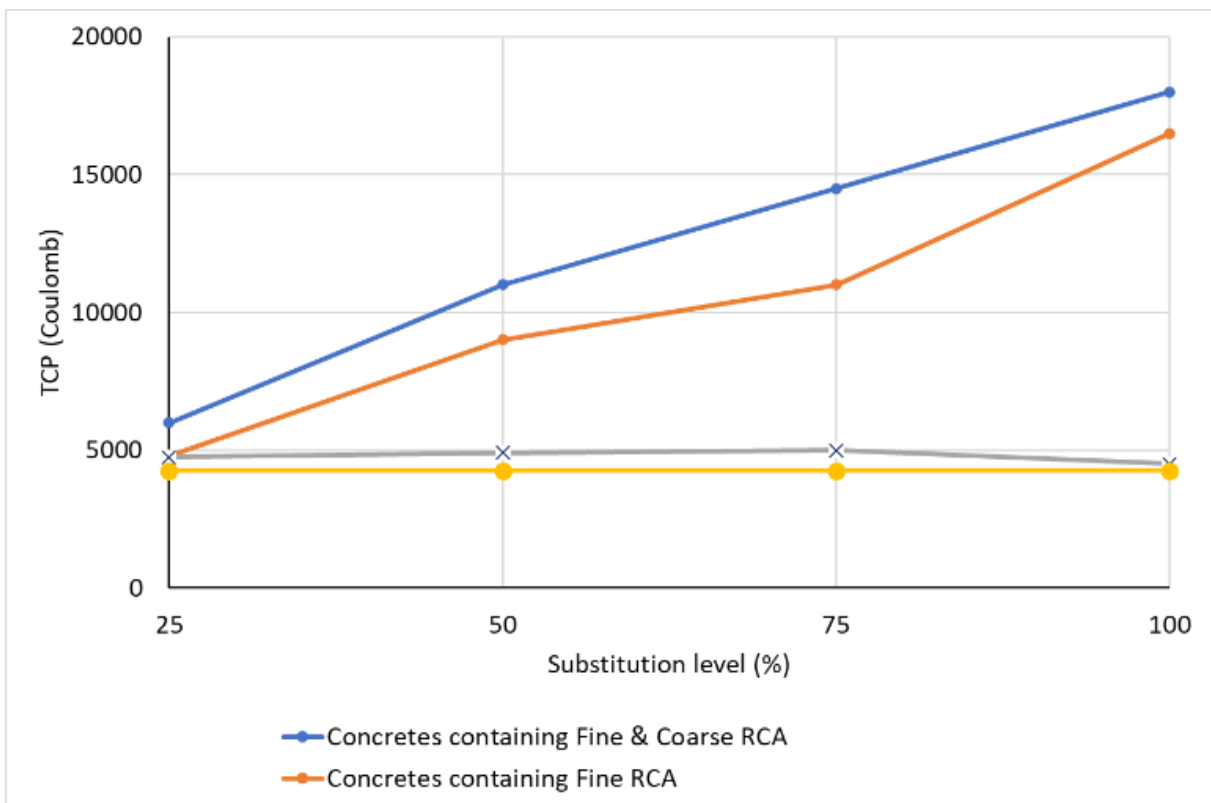


Figure 4d. The effect of chloride ion penetration in Ras, the effect of all mixture at 28 days

Total charge transmission increased dramatically with the rise in replacement, rising by 19.3% in comparison to the reference. For the S50f and S75f, respectively, this rise was more than 2.5 and 3 times more than the reference. It climbed 4.5 times more than that in the reference when the 100% fine RCA was replaced. The mortar's permeable composition that adhered to the repurposed fine aggregates was the reason for this. By combining RCAs, the test specimens' current passing efficiency gradually increased with time. The findings suggest that combining RCAs with fine and coarse resolutions significantly increased charge transmission, while significantly reducing chloride ion penetration. Because of the great permeability of recycled fine aggregates and the strong adhesion of the mortar, further to the effects of electrical resistance and water absorption, fine RCA is the essential component lowering the chloride ion resistivity, as can be seen in Fig. 4d. This rise for the S25Cf, S50Cf, S75Cf and S100Cf was more than 1.9, 3.3, 4.3, and 5 times higher than the reference.

### 3.6. Correlation

The coefficient of correlation  $R^2 = 0.8841$  indicates that ER and PV have a strong linear relationship. When PV is increased, ER will also go down. By comparing the findings of the  $Cl^+$  penetration experiment with the PV results, it revealed that there is a highly clear association between PV and charge transmission, with  $R^2 = 0.9277$  is the correlation coefficient. Reduce the resistance to  $Cl^+$  penetration to increase PV in concrete. The total charge transmission and ER are properly correlated, with  $R^2 = 0.812$  serving as the coefficient of correlation. The total charge transmission is anticipated to drop and chloride ion penetration resistance to increase with an increase in ER.

## 4. Conclusions

This study examined how RCA waste, both coarse and fine, affected the durability and mechanical characteristics of concrete that self-compacts. The study's experimental findings and comments can be used to draw the conclusions on how the durability and mechanical characteristics are impacted by recycled coarse and fine aggregates. The compacting power of SCC is significantly impacted when RCA is utilized in place of Natural Coarse Aggregates (NCA), either completely or partially.

- When RCA is used as a partial or complete replacement for organic components, the CS of SCC is diminished. 32 to 42% in concrete comprising coarse RCA, and 52% in concrete comprising fine RCA. Combining coarse and fine RCA decreases the CS by a maximum of 27%.
- The presence of RCAs has a detrimental effect on the durability characteristics of SCCs, such as the volume of permeable voids and immersion absorption. Due to the increased water absorption of RCAs, water absorption and permeability spaces expand. SCCs with greater water absorption were discovered in mixtures containing fine RCAs (up to 193% according to BS, 171% according to ASTM, and 78% and 109% according to BS).
- Adding RCAs has a detrimental effect on the performance of SCC mixes. A rise in the percentage of RCAs being replaced correlates with a decrease in electrical resistance and an increase in the overall amount of charge transmitted. This will increase the total charge flow in concrete containing refined RCAs. However, electrical resistivity and  $Cl^+$  resistance were not changed by the replacement of 25% of the coarse RCAs.
- Durability tests such as Permeable Voids and water absorption, Electrical Resistivity, Correlation Rapid Chloride Penetration test of proposed concrete were conducted and notified the results. Utilizing RCAs reduces the UPV in SCCs; however, altering the replacement cost in dollars has no effect on the magnitude of the reduction.

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