Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 10, Special Issue, 2024

"Sustainable Infrastructure and Structural Engineering: Innovations in Construction and Design"

The Influence of Recycled Coarse Aggregate Content on the Properties of High-Fly-Ash Self-Compacting Concrete

Hung Cuong Nguyen [1*]

[1] *Faculty of Building and Industrial Construction, Hanoi University of Civil Engineering, Hanoi, Vietnam.*

Received 29 November 2023; Revised 07 April 2024; Accepted 02 May 2024; Published 26 May 2024

Abstract

In Vietnam, solid waste from construction activities significantly impacts environmental pollution. Recycled concrete aggregate (RCA), derived from waste concrete, can serve as a coarse aggregate in concrete production. However, compared to natural aggregates, RCA exhibits distinct characteristics, including lower strength, higher water absorption, and an increased angular and rough surface. These properties may influence concrete's workability, compressive strength, and durability. This research investigates the influence of RCA on the properties of High-Fly-Ash Self-Compacting Concrete (SCC). The study explores various replacement levels of natural coarse aggregate with RCA (0%, 50%, 75%, and 100%), alongside a 50% volume fraction of fly ash. Key concrete properties evaluated include workability, compressive strength, flexural strength, and chloride ion permeability. The findings reveal that using 100% RCA in combination with a high fly ash content (50%) produces SCC that meets workability requirements according to EFNARC standards. However, there are trade-offs: the compressive strength decreases by 4.61%, the flexural strength decreases by 3.1%, and chloride ion permeability increases by 57.57% compared to the control sample (using natural aggregates). Notably, the chloride ion permeability of SCC using 100% RCA falls into the category of low permeability.

Keywords: Self-Compacting Concrete; Recycled Concrete Aggregate; Workability; Compressive Strength; Flexural Strength; Chloride Ion Permeability.

1. Introduction

In the context of rapid urban development in Vietnam, the demand for construction and infrastructure upgrades has become a significant priority. Consequently, a large amount of non-degradable solid waste is generated, particularly from construction activities. Studies conducted in Hanoi for the year 2021 revealed that daily solid waste from construction activities amounted to 4,186 tons/day and is projected to reach 9,431 tons/day by 2025. However, only 1,350 tons of solid waste are currently treated per day [1]. Untreated construction waste has a considerable negative impact on the environment and urban landscape. Although the government encourages the collection and recycling of construction waste for building material production, as stated in Decree No. 09/2021/NĐ-CP and Decision No. 1266/QĐ-TTg on August 18, 2020, issued by the Prime Minister, the recycling and utilization of construction waste for producing new materials still face numerous challenges.

Recycled Concrete Aggregate (RCA) consists of by-products or structures from old concrete that are processed and reused to manufacture new concrete. Utilizing RCA in concrete production offers a dual benefit: it reduces solid waste

* Corresponding author: cuongnh@huce.edu.vn

http://dx.doi.org/10.28991/CEJ-SP2024-010-04

while decreasing the consumption of natural mineral resources, thereby contributing to environmental protection. Moreover, incorporating RCA into new concrete structures aligns with the principles of a circular economy, effectively closing the concrete loop [2]. The structure of RCA includes both the original aggregate part and the aged bonding mortar layer. Consequently, RCA exhibits distinct properties compared to natural coarse aggregates, including higher water absorption, specific volume variations, and reduced mechanical strength [3, 4]. Additionally, RCA surfaces tend to be rougher and more angular [5]. The use of RCA affects the transition zone between the concrete mortar layer and the aggregates, leading to lower compressive and tensile strength compared to natural aggregates [6]. Furthermore, the carbonation process in concrete tends to increase proportionally with the RCA content. The penetration of chloride ions also increases in proportion to the RCA content, as ion movement depends on the permeability of the concrete and the water absorption of the original mortar layer adhering to the coarse aggregates [6]. The high-water absorption capacity and porous structure of RCA significantly affect the workability of the concrete mix [7].

Self-compacting concrete (SCC) represents a specialized type of concrete characterized by high consistency and excellent workability. Unlike traditional concrete, SCC can flow through formwork corners under its own gravity without requiring external vibration forces, ensuring robust compaction [8]. While SCC offers several advantages, including rapid construction, reduced labor dependency, improved working conditions, noise reduction, and environmental benefits, it still faces challenges related to material costs and quality control. The elevated cement content and chemical admixture requirements contribute to these higher costs [4]. Therefore, it is essential to explore alternative materials such as recycled aggregates and high-volume fly ash to reduce SCC production costs.

Fly ash is also a waste product from the thermal power industry. Studies demonstrate that utilizing high-volume fly ash significantly lowers SCC production costs [9]. Notably, fly ash contributes to reduced permeability, decreased water demand, and moderated heat of hydration while increasing the SCC workability [10]. Therefore, the simultaneous use of recycled coarse aggregates and high-volume fly ash in SCC production can overcome some of the limitations associated with concrete using recycled coarse aggregates [11]. This approach facilitates cost-effective SCC production, reduces resource consumption, and promotes environmental sustainability.

The history of SCC, particularly when utilizing RCA, remains relatively short. However, since the inception of SCC using RCA, many studies have explored various aspects, demonstrating its practical applications in industrial contexts [12]. Several international studies on the use of RCA in SCC, such as Panda & Bal [13], revealed a decrease in the compressive, flexural, and tensile strengths of SCC when RCA content increases. Tang et al. research [14] suggests that using 25–50% RCA had minimal adverse effect on the workability, strength, and durability of concrete, except for a slight reduction in modulus of elasticity. Rizwan et al.'s [15] study showed that an increase in viscosity with increasing RCA replacement in the concrete mix leads to reduced flowability. The compressive strength of SCC decreased by 30%, and its flexural strength decreased by 15% when replacing 100% RCA. The chloride ion permeability of SCC was reduced by 57.57% compared to the control sample using natural aggregates. The chloride ion permeability of SCC using 100% RCA was classified as low. Additionally, studies by Jagadesh et al. [16] and Martínez et al. [17] demonstrated the feasibility of replacing 100% RCA to produce sustainable SCC. On the other hand, Yu et al. [18] investigated the flexural strength of SCC using a four-point bending test, revealing similar failure patterns, moment-deflection curves, and bending capacities between the samples. Meanwhile, the crack moment and crack width of SCC samples using RCA were smaller than those using natural aggregates.

Ahmed et al. [19] demonstrated the feasibility of utilizing RCA to produce SCC with 100% RCA replacement with minimal impact on the concrete properties. The optimal SCC mix with 100% RCA replacement, 20% metakaolin, and 22% fly ash met the workability requirements according to EFNARC standards. Using 100% RCA resulted in an 8.2% decrease in compressive strength compared to the control sample. Tang et al. [20] investigated the impact of mechanical sieving on the basic properties of RCA and SCC. The results indicated that the mechanical sieving of RCA reduced its water absorption from 6.22% to 5.33%. Sieving of RCA enhanced the compressive strength of SCC at 28 days by 15–28% compared to samples without sieved RCA. Similarly, the results regarding tensile strength and modulus of elasticity also increased with compressive strength. The microstructure of SCC using sieved RCA was comparable to that of the control concrete structure, with minimal voids and cracks along the surface transition zones. Furthermore, Lekshmy et al. [21] demonstrated that the combined use of coarse and fine RCA reduced the compressive strength of SCC by approximately 27%. The presence of RCA adversely affected the strength of the SCC. The water absorption capacity of SCC increased when using fine RCA, and increasing the RCA ratio increased the charge transfer through SCC.

However, it is evident that studies related to SCC using RCA have been conducted and published incompletely and with unclear focus. Existing research primarily centers on evaluating the effects of RCA usage on the workability, hardening properties, and durability of SCC. However, there remains a significant gap in understanding the properties of SCC when simultaneously incorporating both RCA and a high volume of fly ash. Furthermore, the lack of waste classification from construction activities and the absence of RCA production crushing facilities have posed significant challenges to the research and application of SCC using RCA in Vietnam. Meanwhile, the trend towards the development and application of SCC (especially low-cost SCC) in practical construction in Vietnam is increasingly evident and growing.

In this study, the author explores the influence of RCA content on the properties of SCC alongside a high volume of fly ash. The RCA content levels considered are 0%, 50%, 75%, and 100%. The evaluated properties included the workability, compressive strength, flexural strength, and chloride ion permeability of SCC. The purpose of this article is to clarify the influence of recycled coarse aggregate (RCA) ratios on the properties of high-fly ash content self-compacting concrete (SCC) under Vietnamese material and climatic conditions. Figure 1 illustrates the summarized process flow for conducting the study on the properties of SCC using RCA.

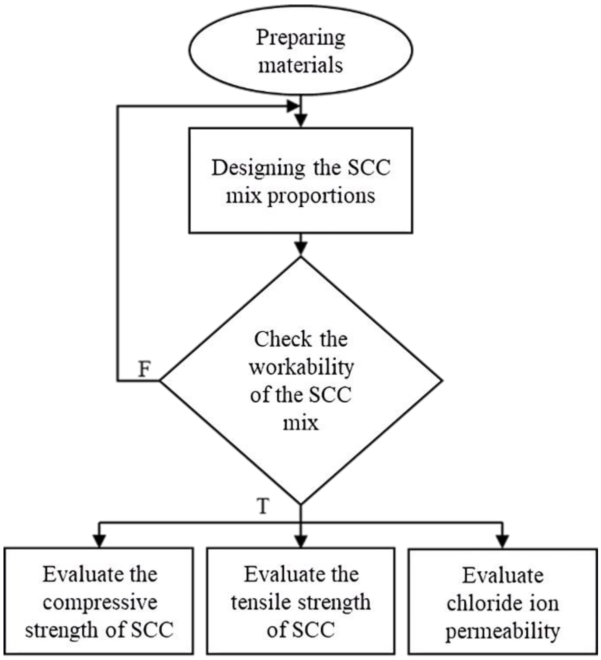

Figure 1. Summary process flow of conducting the study on the properties of SCC using RCA

2. Significance of the Research

Solid waste generated from construction activities in Vietnam has a serious impact on the environment and urban landscapes. However, these waste materials can be effectively repurposed as aggregates in the concrete industry. The study investigates the influence of RCA content on the properties of SCC with a high proportion of fly ash. The properties evaluated include the workability, compressive strength, tensile strength, and chloride ion permeability of SCC. Experimental research results demonstrate that the use of 100% RCA, in combination with a high fly ash content (50%), can produce SCC that meets the EFNARC requirements. The compressive and flexural strengths are slightly lower (by less than 5%) compared to natural aggregate control samples, and the chloride ion permeability is classified as low. Consequently, it is feasible to manufacture SCC that fulfills the technical specifications for structural construction while conserving resources, promoting environmental sustainability, and offering a cost-effective advantage.

3. Materials and Experimental Mix Design

3.1. Materials Utilized

The materials employed in the experiment: Vincem But Son PCB40 cement; golden sand from the Lo River, sieved to exclude particles with a diameter above 5 mm; coarse aggregates (CA) - crushed stone with D_{max} = 20 mm, density of 2.75 g/cm^3; RCA with D_{max} = 2 cm, density of 2.62 g/cm^3; fly ash: F-type fly ash from the Pha Lai thermal power plant, meeting ASTM C618 standards; superplasticizer (SD): BiFi-HV298, a new-generation superplasticizer with an improved polymer base, density of 1.05, compliant with ASTM C-494 Type G; and viscosity-modifying agent (VMA): CuLminal MHPC400. The particle composition of CA, RCA, and sand is depicted in Figure 2.

RCA used in the study was sourced from waste concrete derived from demolished structures in Hanoi. It was then crushed at the crushing station in Dong Anh district of Hanoi. The recycled coarse aggregate meets the criteria specified in TCVN 11969:2018 [22]. Figure 3 provides images of the recycled coarse aggregate.

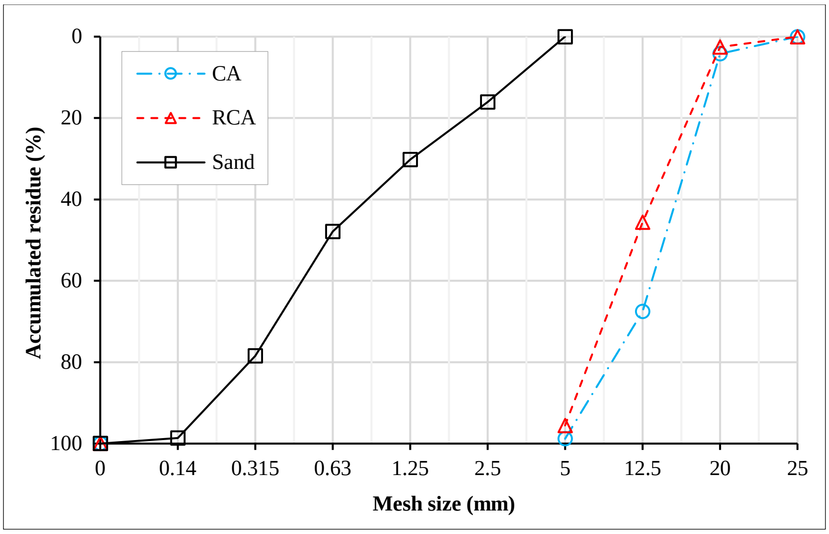

Figure 2. Particle size distribution curve of CA, RCA, and sand

Figure 3. RCA used in the production of SCC

3.2. Experimental Concrete Mix Design

The mix design of SCC was conducted according to the method proposed by the Japan Society of Civil Engineers (JSCE) [23]. Specifically, coarse aggregates constituted 50% of the concrete volume, fine aggregates made up 40% of the mortar volume, and the Water/Powder (W/P) ratio by volume was adjusted between 0.9 and 1. The RCA ratio surveyed was selected based on the study by Lekshmy et al. [21], including 0%, 50%, 75%, and 100%. According to the previous study [9], SCC with a 50% replacement of fly ash can achieve compressive strength ranging from 20-40MPa and is not more expensive than traditional concrete. Additionally, concrete using fly ash content above 50% is referred to as high-fly ash content concrete [24]. Therefore, to ensure that SCC has adequate compressive strength, workability, and reasonable cost, the study chose the Fly ash/Powder (FA/P) ratio = 0.5 and the water/powder ratio by weight (W/P) = 0.38. The detailed composition of SCC mixtures is shown in Table 1.

Table 1. SCC Mix Designs

Mix	RCA/CA	Cement PCB40 (kg)	Fly Ash (kg)	Sand (kg)	Stone (kg)	RCA (kg)	Water(kg)	SD (kg)	VMA (kg)
RCA 0	0%	282.4	282.4	748.8	770	0	214.6	2.86	0.21
RCA 50	50%	282.4	282.4	748.8	385	385	214.6	3.69	0.21
RCA 75	75%	282.4	282.4	748.8	192.5	577.5	214.6	4.04	0.21
RCA 100	100%	282.4	282.4	748.8	0	770	214.6	4.70	0.21

4. Experimental Results

4.1. SCC Workability Test

The workability of the SCC was assessed following the TCVN 12209:2018 guidelines [25]. The parameters tested included slump flow (SF), time of slump flow (T_{500}), J-ring passing ability (J_{ring}), L-box passing ability (L_{box}), V-funnel flow time (V_{funnel}), and segregation resistance (Sr). As per [26], the expected ranges for these parameters are as follows: slump flow (SF) should be between 650-800mm, T_{500} flow time should be within 2-5 seconds, J_{ring} values should be between 0-10mm, V_{funnel} flow time should be between 6-12 seconds, and segregation resistance (Sr) should range from 5-15%. Table 2 presents the experimental results for the SF, T500, Jring, Lbox, Vfunnel, and Sr parameters.

Table 2. Workability test results according to TCVN 12209:2018 [25]

Mix	SF (mm)	T_{500}(second)	V_{funnel} (second)	L_{box}	J_{ring} (mm)	Sr (%)
RCA 0	720	3.10	9.5	0.91	8.6	8.7
RCA 50	710	3.75	9.9	0.87	8.9	7.8
RCA 75	705	4.35	10.7	0.85	9.5	7.2
RCA 100	700	4.80	11.5	0.82	9.8	6.9

The Slump Flow (SF) of all mixtures in the experiment varied between 700 mm and 720 mm. All mixtures exhibited T_{500} flow times ranging from 3.10 seconds to 4.80 seconds and V_{funnel} flow times between 9.5 seconds to 11.5 seconds. The mixtures passed the L_{box} test with values ranging from 0.82 to 0.91 and the J_{ring} test with values from 8.6 to 9.8 mm. All mixtures demonstrated excellent flowability, with no blockages encountered at any stage. The segregation resistance of the mixtures ranged from 6.9% to 8.7%. Figure 4 illustrates the workability test process of SCC.

(a) The SF test (b) The L_{box} test (c) The Sr test

Figure 4. SCC workability test experiment

The experimental results suggest that an increase in the RCA content leads to a reduction in the slump flow for SCC mixtures. When using RCA at 50%, 75% and 100%, the slump flow decreased by 1.3%, 2.08% and 2.8% respectively, compared to the mixture without RCA. It can be observed that the slump flow values for mixtures using RCA decrease by less than 3% compared to the mixture without RCA. However, to achieve this minor difference, mixtures using RCA had to significantly increase the amount of superplasticizer. Specifically, for mixtures with 50%, 75%, and 100% RCA content, the dosage of SD increased by 29.02%, 41.2%, and 64.3% respectively (Figure 5). Additionally, with increasing RCA content, the viscosity of SCC mixtures increased, as indicated by the increased T_{500} and V_{funnel} flow times. Moreover, when using 50%, 75% and 100% RCA content, the Sr of mixtures tended to decrease compared to the mixture without RCA, decreasing by 10.3%, 17.2% and 20.6% respectively. Since mixtures with high fly ash content and a higher dosage of SD, combined with the use of VMA, the mixture with a maximum 100% RCA content still has good passing ability, as demonstrated by the L_{box} value of 0.82 > 0.8 and J_{ring} value of 9.8 mm < 10 mm (Table 2). Thus, the combination of high fly ash content with chemical admixtures can mitigate the drawbacks of RCA to enhance the workability of SCC.

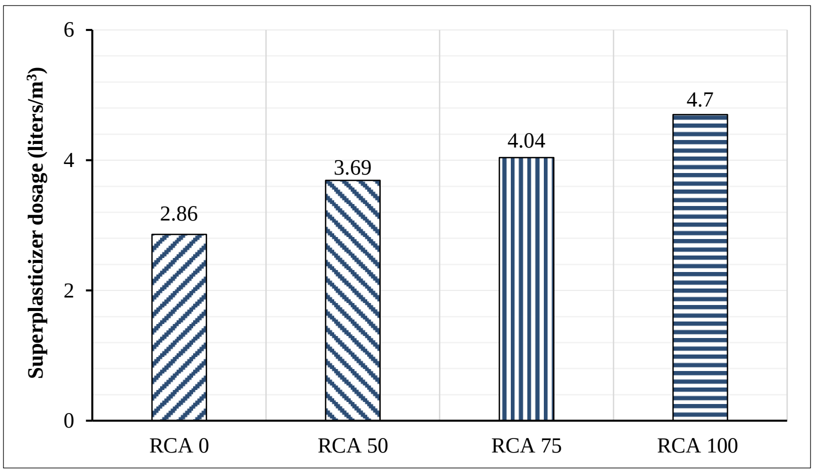

Figure 5. Superplasticizer dosage for SCC mixes

Due to the presence of old mortar adhering to the aggregates, the water absorption of RCA is higher than that of natural aggregates. When RCA is dry, it absorbs water used in the mortar mixing, leading to a reduction in the workability of SCC. In this study, to elucidate this phenomenon, mixtures were evaluated by conducting slump flow tests every 30 minutes during a 120-minute holding period. The tests were carried out under hot and humid fall weather conditions (September 2023), with a temperature of 36°C and humidity of 65%. The analysis of the experimental results is presented in Figure 6, demonstrating a clear influence of holding time and RCA content on the workability of SCC.

For the control mix, RCA0, the SF was well maintained, meeting the usage criteria (>=650mm) even after 120 minutes of holding. As the RCA content increased to 50%, the RCA 50 mix retained good SF, meeting the criteria after 90 minutes. However, with 75% RCA content (RCA 75), the slump flow could only meet the usage criteria within 60 minutes. Particularly, at the maximum RCA content condition (100% RCA), the slump flow of the RCA 100 mix significantly decreased, falling below the usage criteria after 45 minutes of holding. The rapid reduction in workability when increasing the RCA content is a big disadvantage of using RCA in SCC, especially under the hot and dry weather conditions typical of Vietnam's summers. Therefore, to ensure the workability of SCC, regulations on the transportation time of SCC mix should be established based on the RCA content used and environmental factors such as temperature and humidity. Figure 6 illustrates the slump flow reduction of SCC over time.

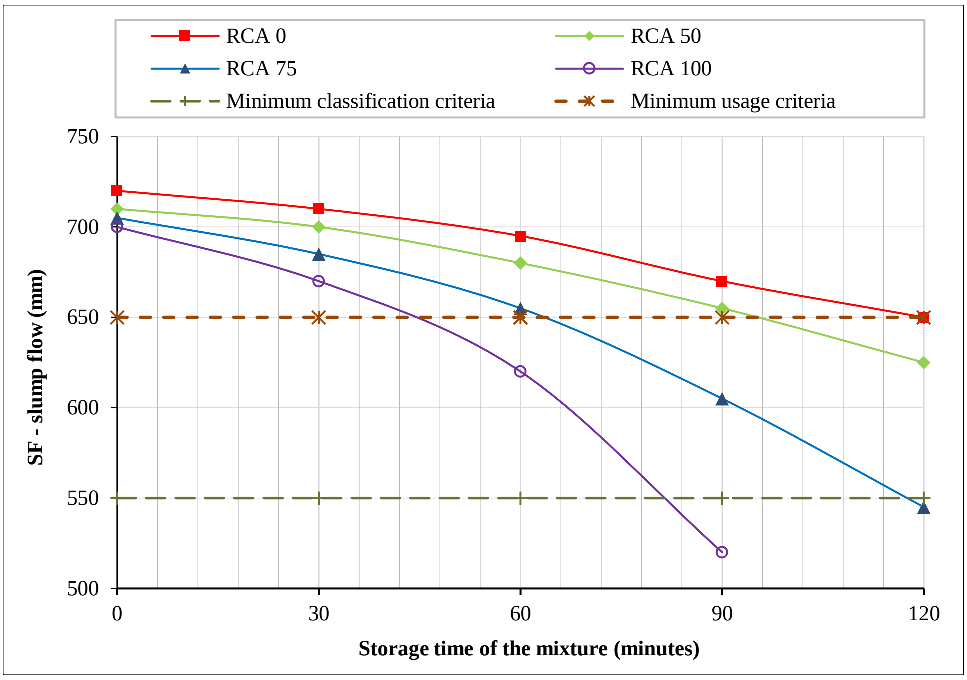

Figure 6. Slump flow reduction over time as a function of RCA ratio in SCC mixes

4.2. Compressive Strength Test Results for SCC

Concrete samples were prepared and cured following the guidelines of TCVN 3105:2022 [27]. The compression strength specimens had dimensions of 10×10×10 cm. The samples were initially cured under standard conditions and then immersed in water from the second day. The compressive strength testing was conducted according to TCVN 3118:2022 [28]. The compression tests were performed using a 200-ton hydraulic press DHR 200. Table 3 and Figure 7 present the compressive strength results of various SCC mixes.

Table 3. Compressive Strength of SCC Mixes

Mix	Compressive Strength (MPa)		% Variation in Compressive over Control Mix	
	7 days	28 days	7 days	28 days
RCA 0	17.01	30.9	0	0
RCA 50	15.16	26.6	10.8	13.9
RCA 75	14.33	24.7	15.7	20.1
RCA 100	16.23	29.5	4.60	4.61

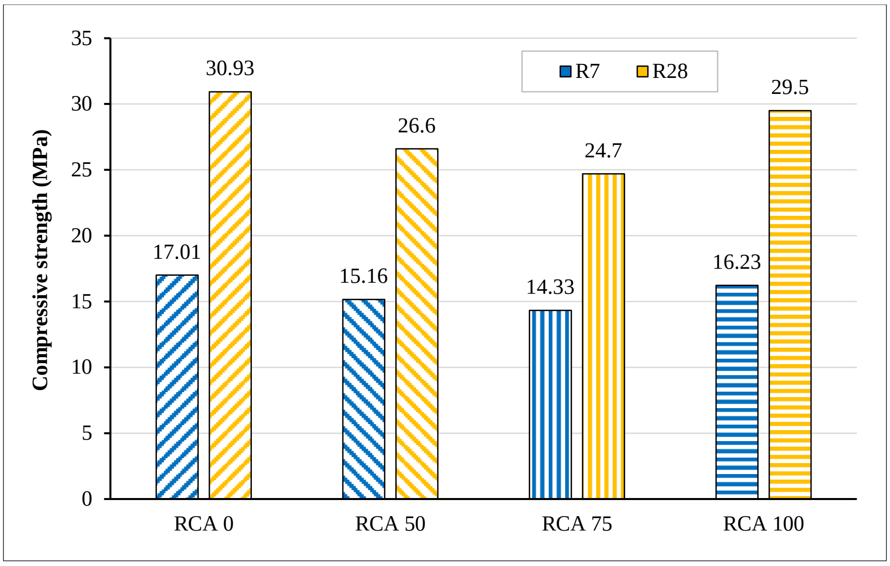

Figure 7. Experimental Results of Compressive Strength for Various SCC Mixes

Compressive strength of RCA 0, RCA 50, RCA 75 and RCA 100 mixes at 7 days were 17.01 MPa, 15.16 MPa, 14.33 MPa and 16.23 MPa, respectively. At 28 days, the values were 30.93 MPa, 26.6 MPa, 24.7 MPa and 29.5 MPa, respectively. The experimental results indicate that the use of RCA at 50%, 75% and 100% reduces the compressive strength of SCC at 28 days compared to the mix without RCA by 13.9%, 20.1% and 4.61%, respectively. These results are relatively consistent with previous studies. Rizwan et al. [15] demonstrated that SCC with a ratio (W/P=0.38) using 100% RCA reduced the concrete compressive strength by approximately 9.4% compared to the mix without RCA. In a study by the Quang et al. [29], concrete using 50% and 100% RCA had compressive strengths at 28 days lower than the control mix without recycled aggregate by 15.97% and 9.5%, respectively. In addition, the results also showed that concrete using 50% RCA had lower compressive strength than using 100% RCA. The lower compressive strength of samples using RCA compared to control samples is attributed to the weak remaining mortar layer on the RCA, leading to lower density and higher porosity, which in turn results in reduced compressive strength [15]. Moreover, the higher water absorption of RCA compared to natural aggregate can lead to excessive water absorption by the SCC mix, leaving insufficient water for cement hydration, thereby influencing the compressive strength of SCC. This is the reason why samples using 100% RCA have lower compressive strength than control samples [30].

4.3. Flexural and Tensile Strength Test Results for SCC

Concrete samples were cast and then cured in accordance with the TCVN 3105:2022 [27]. The specimens had dimensions of 150×150×600. The determination of the tensile strength along the axis of the concrete was carried out following the guidelines of the TCVN 3119:2022 [31]. Table 4 and Figure 8 present the flexural and tensile strength test results for SCC.

The flexural strength results for SCC are similar to the compressive strength results. Increasing the content of RCA reduces the flexural strength of SCC samples. The flexural strength (Rku) of RCA 0, RCA 50, RCA 75 and RCA 100 mixes are 3.91 MPa, 2.93 MPa, 2.69 MPa and 3.79 MPa, respectively. The flexural strength (Rk) of SCC with RCA content of 50%, 75%, and 100% decreases by 25%, 31% and 3.1%, respectively, compared to the mix without RCA. These research findings align well with previously published results. Grdic et al. [32] study indicates a 2.5% - 14% reduction in concrete tensile strength when using 50% and 100% RCA compared to the control sample. Tuyan et al. [4] showed that using RCA content from 20% to 60% reduces flexural strength by 8.8% - 16% due to higher porosity and lower density of RCA compared to natural coarse aggregates.

Comparing the flexural strength requirements in TCVN 3118:2022 [28] (Table 4), it is evident that both RCA 0 and RCA 100 mixes meet the correlation requirement between compressive and flexural strength. However, RCA 50 and RCA 75 mixes exhibit lower flexural strength values compared to the required correlation. This indicates that using entirely RCA can produce concrete structures that meet the strength requirements for structural elements. Meanwhile, simultaneously using recycled coarse aggregates and natural coarse aggregates may result in non-uniform strength characteristics due to the water absorption of RCA, impacting the compressive and flexural strength of SCC. Hence, the flexural strength values with 50% and 75% RCA content are lower than the mix with 100% RCA.

Table 4. Flexural and Tensile Strength of Various SCC Mixes

Symbol	Flexural Strength Rku (MPa)	Tensile Strength Rk (MPa)	Flexural Strength Requirement (MPa)	Percentage Reduction in Flexural Strength
RCA 0	3.91	2.27	3.71	0.0
RCA 50	2.93	1.70	3.19	25.0
RCA 75	2.69	1.56	2.96	31.0
RCA 100	3.79	2.20	3.54	3.1

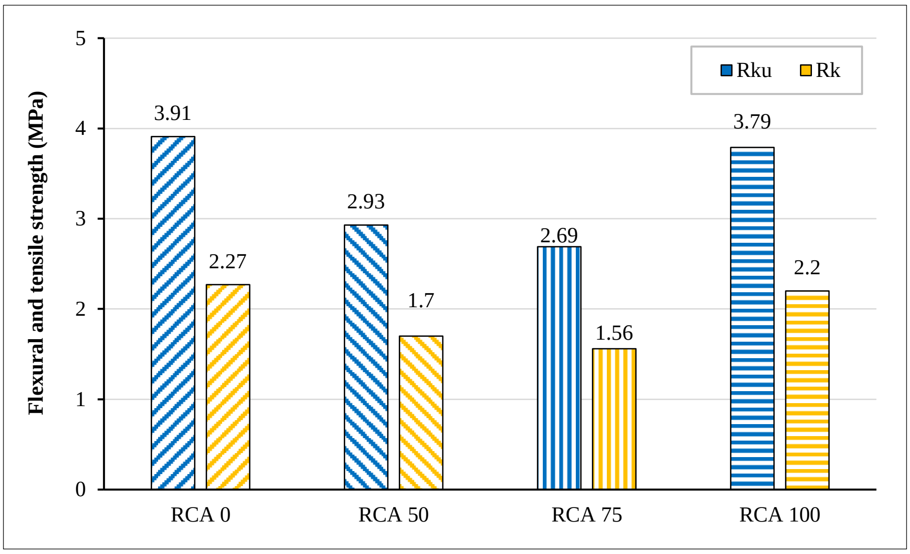

Figure 8. Experimental Results of Flexural and Tensile Strength for Various SCC Mixes

4.4. Chloride Ion Permeability

The chloride ion permeability of the concrete was assessed using the Chloride Permeability Test (CPT) method, following the guidelines of TCVN 9337:2012 [33]. In this test, a direct current was applied through a cylindrical specimen (100 mm in diameter, 50 mm in height). One face of the specimen was in contact with a 3% NaCl solution connected to the negative electrode, while the other face was in contact with a NaOH solution connected to the positive electrode. The chloride ion permeability was determined by measuring the charge passed through the specimen over a 6-hour period. Figure 9 illustrates the specimen preparation and the CPT process.

(a) RCA 100 (b) RCA 100 (c) The CPT method

Figure 9. Sample preparation and the CPT for Various SCC Mixes

The test results, shown in Figure 10, indicate that at the age of 28 days, the charge passed through the concrete specimens with RCA ratios of 0%, 50%, 75%, and 100% was 1096 C, 1856 C, 2392 C, and 1727 C, respectively. The results demonstrate that increasing the RCA content by 50%, 75%, and 100% resulted in an increase in the charge passed through the specimens by 69.34%, 118.24%, and 57.57%, respectively, compared to the specimens without RCA. This is attributed to the initial mortar layer adhering to the coarse aggregates, increasing the porosity and permeability of the SCC. Additionally, chloride ion movement depends on the permeability and water absorption of the coarse aggregates [6].

In line with the compressive strength tests results, the use of 50% and 75% RCA led to a greater increase in chloride ion permeability compared to using 100% RCA. These observations consistent with the findings of Lekshmy et al. [21]

on the chloride ion permeability. Specifically, an increase in charge transfer through SCC was noted when using various RCA ratios. However, in Lekshmy et al. [21] study, there was an additional step of removing the maximum amount of residual old mortar on the surface of RCA, so the degree of increase in charge transfer through SCC was smaller. Notably, when using 100% RCA, the charge passed through the concrete ranged from 1000-2000 C, indicating low permeability according to TCVN 9337:2012 [33]. This is due to the superior ability of fly ash particles to absorb and bind chloride ions compared to cement particles, which significantly reduces their movement. This suggests that the use of a high content of fly ash has partially mitigated the RCA's drawback of increasing chloride ion permeability. As a result, SCC incorporating RCA exhibits low chloride ion permeability.

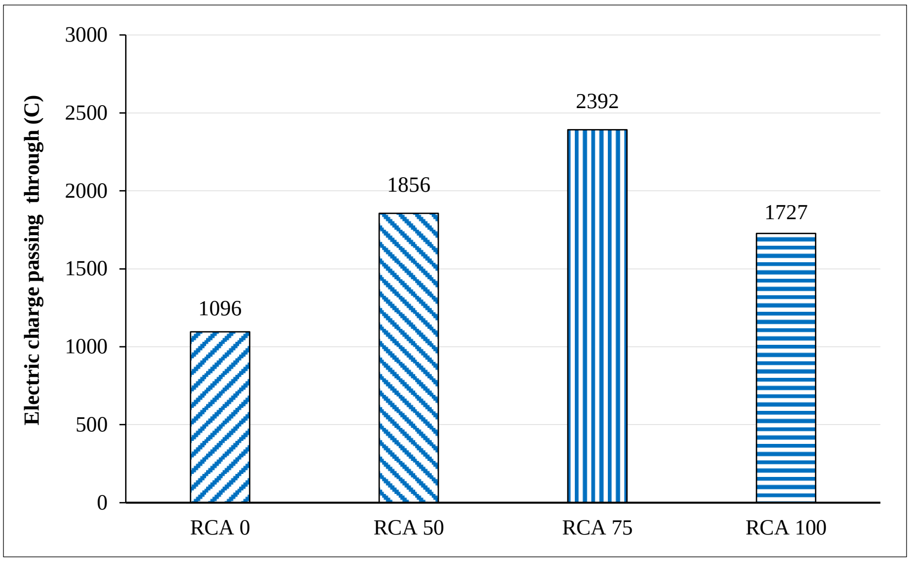

Figure 10. CPT Test Results for Various SCC Mixes

5. Conclusion

The research findings validate the potential of using RCA to produce SCC that meets the EFNARC requirements. This is achieved by incorporating a high proportion of fly ash and increasing the dosage of superplasticizer. It is noteworthy that an increase in RCA content enhances the viscosity and segregation resistance of the SCC mixtures. For the mixture with 100% RCA, to maintain workability equivalent to SCC using natural aggregates, the dosage of superplasticizer needs to be increased by approximately 64.3%. In the hot and humid climate of Vietnam (temperature of 36°C, humidity of 65%), a mixture using 100% RCA can maintain the required SF for about 45 minutes.

The compressive strength of SCC decreases with the use of RCA. Specifically, when using RCA contents of 50%, 75%, and 100%, the compressive strength decreases by 13.9%, 20.1%, and 4.61%, respectively, compared to the control sample. Similarly, the flexural strength of SCC decreases in proportion to the compressive strength with the use of RCA. With RCA content of 50%, 75%, and 100%, the flexural strength decreases by 25%, 31%, and 3.1%, respectively, compared to the control sample. The chloride ion permeability increases in proportion to the RCA content in the mix. Specifically, with RCA content of 50%, 75%, and 100%, the chloride ion permeability increases by 69.34%, 118.24%, and 57.57%, respectively. The incorporation of high fly ash content significantly reduces chloride ion permeability. In the case of using 100% RCA, the charge transfer through the SCC sample is 1727C, which is classified as having low chloride ion permeability.

6. Declarations

6.1. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.2. Funding

The author received no financial support for the research, authorship, and/or publication of this article.

6.3. Conflicts of Interest

The author declares no conflict of interest.

7. References

[1] Hanh, V.K., & Huyen, N.T. (2022). Research on construction solid waste management in Hanoi in the direction of circular economy. Environment Magazine, 1(1), 3-7.

[2] Marinković, S., Josa, I., Braymand, S., & Tošić, N. (2023). Sustainability assessment of recycled aggregate concrete structures: A critical view on the current state-of-knowledge and practice. Structural Concrete, 24(2), 1956–1979. doi:10.1002/suco.202201245.

[3] Tu, T. Y., Chen, Y. Y., & Hwang, C. L. (2006). Properties of HPC with recycled aggregates. Cement and Concrete Research, 36(5), 943–950. doi:10.1016/j.cemconres.2005.11.022.

[4] Tuyan, M., Mardani-Aghabaglou, A., & Ramyar, K. (2014). Freeze-thaw resistance, mechanical and transport properties of self-consolidating concrete incorporating coarse recycled concrete aggregate. Materials & Design, 53, 983–991. doi:10.1016/j.matdes.2013.07.100.

[5] Padmini, A. K., Ramamurthy, K., & Mathews, M. S. (2009). Influence of parent concrete on the properties of recycled aggregate concrete. Construction and Building Materials, 23(2), 829–836. doi:10.1016/j.conbuildmat.2008.03.006.

[6] Santos, S., da Silva, P. R., & de Brito, J. (2019). Self-compacting concrete with recycled aggregates – A literature review. Journal of Building Engineering, 22, 349–371. doi:10.1016/j.jobe.2019.01.001.

[7] Ryan, P. C., & O'Connor, A. (2014). Examination of Self-Compacting Concrete Options for Marine Bridge Applications. Journal of Bridge Engineering, 19(9), 04014032. doi:10.1061/(asce)be.1943-5592.0000541.

[8] Elevado, K. J. T., Galupino, J. G., & Gallardo, R. S. (2018). Artificial Neural Network (ANN) modelling of concrete mixed with waste ceramic tiles and fly ash. GEOMATE Journal, 15(51), 154–159. doi:10.21660/2018.51.58567.

[9] Bouzoubaâ, N., & Lachemi, M. (2001). Self-compacting concrete incorporating high volumes of class F fly ash. Cement and Concrete Research, 31(3), 413–420. doi:10.1016/s0008-8846(00)00504-4.

[10] Douglas, R. P. (2004). Properties of self-consolidating concrete containing type F fly ash. Portland Cement Association, Washinton, United States.

[11] da Silva, S. R., & Andrade, J. J. de O. (2022). A Review on the Effect of Mechanical Properties and Durability of Concrete with Construction and Demolition Waste (CDW) and Fly Ash in the Production of New Cement Concrete. Sustainability, 14(11), 6740. doi:10.3390/su14116740.

[12] Malazdrewicz, S., Adam Ostrowski, K., & Sadowski, Ł. (2023). Self-compacting concrete with recycled coarse aggregates from concrete construction and demolition waste – Current state-of-the art and perspectives. Construction and Building Materials, 370, 130702. doi:10.1016/j.conbuildmat.2023.130702.

[13] Panda, K. C., & Bal, P. K. (2013). Properties of self-compacting concrete using recycled coarse aggregate. Procedia Engineering, 51, 159–164. doi:10.1016/j.proeng.2013.01.023.

[14] Tang, W. C., Ryan, P. C., Cui, H. Z., & Liao, W. (2016). Properties of Self-Compacting Concrete with Recycled Coarse Aggregate. Advances in Materials Science and Engineering, 2016, 1–11. doi:10.1155/2016/2761294.

[15] Rizwan, S. A., Irfan-Ul-Hassan, M., Rahim, A., Ali, S., Sultan, A., Syamsunur, D., & Md Yusoff, N. I. (2022). Recycled Coarse Aggregate for Sustainable Self-Compacting Concrete and Mortar. Advances in Materials Science and Engineering, 2022, 1–12. doi:10.1155/2022/4566531.

[16] Jagadesh, P., Juan-Valdés, A., Guerra-Romero, M. I., Morán-Del Pozo, J. M., García-González, J., & Martínez-García, R. (2021). Effect of design parameters on compressive and split tensile strength of self-compacting concrete with recycled aggregate: An overview. Applied Sciences, 11(13), 6028. doi:10.3390/app11136028.

[17] Martínez-garcía, R., Jagadesh, P., Búrdalo-salcedo, G., Palencia, C., Fernández-raga, M., & Fraile-fernández, F. J. (2021). Impact of design parameters on the ratio of compressive to split tensile strength of self-compacting concrete with recycled aggregate. Materials, 14(13), 3480. doi:10.3390/ma14133480.

[18] Yu, F., Wang, M., Yao, D., & Yang, W. (2022). Study on Flexural Behavior of Self-Compacting Concrete Beams with Recycled Aggregates. Buildings, 12(7), 881. doi:10.3390/buildings12070881.

[19] Ahmed, S., El-Zohairy, A., Eisa, A. S., Mohamed, M. A. E. A. B., & Abdo, A. (2023). Experimental Investigation of Self-Compacting Concrete with Recycled Concrete Aggregate. Buildings, 13(4), 856. doi:10.3390/buildings13040856.

[20] Tang, W., Khavarian, M., Yousefi, A., Landenberger, B., & Cui, H. (2023). Influence of Mechanical Screened Recycled Coarse Aggregates on Properties of Self-Compacting Concrete. Materials, 16(4), 1483. doi:10.3390/ma16041483.

[21] Lekshmy Raghavan, P., & Nalanth, N. (2023). Analysis of Durability in Self Compacting Concrete with Recycled Concrete Aggregates. Civil Engineering and Architecture, 11(4), 1824–1834. doi:10.13189/cea.2023.110413.

[22] TCVN 11969:2018. (2018). Recycled coarse aggregate for concrete. Construction Materials Institute, Ministry of Construction, Hanoi, Vietnam.

[23] Okamura, H., Ozawa, K., & Ouchi, M. (2000). Self-compacting concrete. Structural Concrete, 1(1), 3–17. doi:10.1680/stco.2000.1.1.3.

[24] Hưng, V. V., Phố, Đ. Q., Văn, T. H., & Quang, L. V. (2022). Research on the effects of lime and silica fume content on the physical and mechanical properties of cement mortar using high fly ash content. Journal of Materials & Construction - Ministry of Construction, 12(01), 255. doi:10.54772/jomc.01.2022.255.

[25] TCVN 12209:2018. (2018). Self-compacting concrete - Specification and test method. Construction Materials Institute, Ministry of Construction, Hanoi, Vietnam.

[26] SSC-028 (2005). The European Guidelines for Self-Compacting Concrete. The European Precast Concrete Organization, BIBM 2005, 1-68. Available online: http://www.voscc.dk/_root/media/17621_SCC%20guidelines_may%202005.pdf (accessed on March 2024).

[27] TCVN 3105:2022. (2022). Concrete and Concrete Mixtures - Sampling, Fabrication and Maintenance of Test Samples. Construction Materials Institute, Ministry of Construction, Hanoi, Vietnam.

[28] TCVN 3118:2022. (2022). Hardened concrete – Test method for compressive strength. Construction Materials Institute, Ministry of Construction, Hanoi, Vietnam.

[29] Quang, N. T., Cường, T. V., Tân, N. N., Tân, N. H., & Giang, N. H. (2021). An experimental study on the effect of the proportions of recycled coarse aggregates on the evolution of concrete compressive strength and young's modulus. Journal of Science and Technology in Civil Engineering (JSTCE) - HUCE, 15(1V), 48–59. doi:10.31814/stce.nuce2021-15(1v)-05.

[30] Andreu, G., & Miren, E. (2014). Experimental analysis of properties of high performance recycled aggregate concrete. Construction and Building Materials, 52, 227–235. doi:10.1016/j.conbuildmat.2013.11.054.

[31] TCVN 3119:2022. (2022). Hardened concrete – Test method for flexural tensile strength. Construction Materials Institute, Ministry of Construction, Hanoi, Vietnam.

[32] Grdic, Z. J., Toplicic-Curcic, G. A., Despotovic, I. M., & Ristic, N. S. (2010). Properties of self-compacting concrete prepared with coarse recycled concrete aggregate. Construction and Building Materials, 24(7), 1129–1133. doi:10.1016/j.conbuildmat.2009.12.029.

[33] TCVN 9337:2012. (2012). Heavy concrete - Method for electrical indication of concrete's ability to resist chloride ion penetration. Construction Materials Institute, Ministry of Construction, Hanoi, Vietnam.