SUSTAINABLE AND COST-EFFECTIVE USE OF RECYCLED CONCRETE AGGREGATE IN SELF-COMPACTING CONCRETE

Mohammad Iqbal[1], Mandeep Kaur[2,*]

Abstract

The focus of this study delves into the potential of using a combination of thermally stimulated superplasticizer and recycled aggregate derived from demolished waste as a partial substitute for natural aggregate in Self-compacting concrete (SCC) works. The investigation encompasses three series of mixes i.e., Series I, Series II, and Series III. In Series I, the effect of adding a thermally stimulated superplasticizer at 50°C on the workability of the concrete is examined in mix C2. Series II evaluates the influence of substituting natural coarse aggregate (NCA) with ratios of 0%, 30%, 45%, and 60% of the recycled concrete aggregate (RCA). The mixes were appraised for their fresh, mechanical, and long-term properties of concrete compared to SCC containing 100% NCA. The outcomes demonstrate that incorporating higher proportions of RCA into mixtures leads to a reduction in compressive strength after 28 days of curing with a maximum decrease of 8.3 MPa for the CR0S65 mix from the control CR0S0, which had a strength of 33.9 MPa. Moreover, there was a slight decline in tensile strength, along with an increase in both chloride ion penetration and water penetration. Series III involves the addition of silica fumes to improve the hardened and durability characteristics of the concrete. The fresh properties of concrete were evaluated through Slump flow, T50, V-funnel, and L-box tests.

Keywords recycled coarse aggregate, silica fumes, RCA, SCC, thermally stimulated plasticizer

---

[1]School of Civil Engineering, Lovely Professional University, Phagwara, 144402, Punjab, India
[2]*School of Civil Engineering, Lovely Professional University, Phagwara, 144402, Punjab, India

***Corresponding Author: -** Mandeep Kaur
*School of Civil Engineering, Lovely Professional University, Phagwara, 144402, Punjab, India
Email:- mandeep.kaur@lpu.co.in

DOI: 10.48047/ecb/2023.12.si5a.0593

1. Introduction

India generates 150 million tons of construction and demolition waste(C&D) annually out of which only 1.3% of waste is recycled[1]. The ever-growing modern infrastructure and new construction technologies lead to the demolition of old_structures which are either poorly constructed or have exhausted their life span. Generation of C&D waste from the demolition of buildings and concrete tested in laboratories or fields, which if not disposed of properly, can have severe consequences on the environment and contribute to increased carbon emissions[2]. Moreover, the increased construction in urban areas demands enormous use of natural aggregates, which requires a lot of fossil energy for their extraction and transportation, resulting in scarcity of the natural mineral and damage to the environment. Therefore, utilizing C&D waste in construction as an alternative to natural aggregates can be a sustainable solution for reducing environmental degradation and waste accumulation. Researchers have studied alternative methods to sustain the ecological balance [3], [4], and one such method is the extraction of fine and coarse aggregate from C&D waste as a replacement for natural aggregate. [5]. However, the recycled coarse aggregate (RCA) obtained from C&D waste has more surface roughness and is more angular than natural aggregates. A typical RCA has a mortar layer attached to it of varying thickness and due to the presence of this layer, RCA is porous in nature and thus absorbs more water consequently making RCA inferior to NCA (natural coarse aggregate)[3]–[6]. To address this shortcoming, researchers suggest that RCA should be derived from high-strength concrete which exhibits better intrinsic properties thereby abating deficiency in aggregate undesirable properties. Additionally, RCA can be utilized with high binder content concretes like SCC, high-strength concrete, and high-performance concrete mixes in the form of coarse recycled aggregates (CRA), and fine recycled aggregate (FRA), where the high binder content of the concrete mix can help to improve the inferior properties of the recycled aggregate[2]. This approach can be an effective way to support sustainable construction practices and reduce the exploitation of natural resources.

SCC is a special type of concrete and has gained widespread use in recent years worldwide. In the new world of engineering, SCC is used in important civil works where flowability is of major concern, thus requiring a large amount of cement and superplasticizer. As the name suggests, SCC is self-compacting in nature and finds its application where reinforcement is congested, and compaction using the external vibrators is constrained[7].

Since excessive use of cement and superplasticizer in SCC makes it expensive, designing a cost-effective SCC that retains its characteristics is a major challenge. Several investigations have stated that the addition of RCA and mineral admixtures such as fly ash, ground granulated blast furnace slag, and metakaolin reduces the cost of SCC[8], [9]. Many researchers had investigated that thermal stimulation of SP, which is a type of high-range water reducer (HRWR), improves the fluidity of mortar mix thereby improving its workability and reducing the amount of SP[10], [11]. Therefore, to increase the cost-effectiveness of SCC, this research employed a thermally stimulated superplasticizer, to study the impact on the fresh properties of the SCC mix. The general working mechanism of SP is that a polymer shows a surfactant property and acts as a dispersant to reduce particle segregation. Dispersion of cement particles is achieved by two phenomena viz electrostatic repulsion shown in figure 1 and steric hindrance effect depicted in figure 2[12].

Electrostatic repulsion is produced by the adsorption of negatively charged groups in the SP. Superplasticizers contain negatively charged groups such as sulphonate or carboxylate. When added to the concrete mix, these groups become ionized and form a cloud of negative charges around the cement particles. This cloud of charges creates an electrostatic repulsion between the particles that causes them_to disperse. While as steric hindrance effect is caused by the presence of side-long graft chains in the SP. The polymer chains in the superplasticizer are bulky and thus prevent the cement particles from coming in close contact with each other[11]. This effect creates a barrier between the cement particles, which reduces their attraction to each other and allows for better dispersion in the concrete mixture.

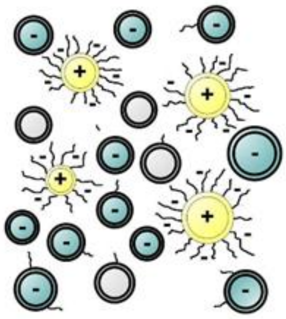

Figure 1. Electrostatic repulsion[13].

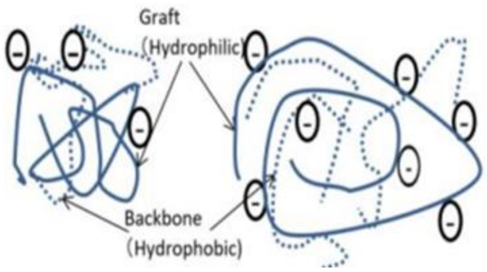

Figure 2. Steric Hindrance Effect[10]

The summary of previous studies provided above indicates that the use of thermal stimulation of SP enhances the flowability of mortar mixes, therefore the study aims to investigate the impact of thermally stimulated SP on the specific combination of concrete materials which include ordinary Portland cement (OPC), fly ash, and different ratios of recycled concrete aggregate (RCA), that has not been studied before in relation to the use of thermally stimulated SP. In this regard, a wide range of properties such as fresh properties, hardened properties, and durability properties are evaluated in different series of mixes. The replacement of RCA for NA in SCC could reduce compressive and tensile strength of the resulting concrete, while also increasing its drying shrinkage and water absorption[14]. This can negatively impact the durability of the concrete. To address this concern and improve the overall characteristics of concrete, Silica fumes, which is a byproduct of the silicon and ferrosilicon alloy production process, formed the basis for enhancing the overall characteristics of concrete in this study[15], [16]. However, the amount of SF in RCA should be carefully controlled to ensure that it does not adversely affect the concrete properties.

Experimental setup

Materials

The various materials employed in this inquiry were set according to the applicable standard regulations i.e., the Indian standard (IS). The SCC mixes investigated had fly ash (FA), silica fume (SF), and ordinary Portland cement (OPC) as their main binders whose chemical properties are depicted in Table1. The OPC utilized was of grade 43 and had a compressive strength of 43 N/mm2 and fineness of 2650 m2/kg. The physical and mechanical properties of OPC conforming to IS: 4031-4/5/6 (1988)[17]–[19] are tabulated in Table2. To advance the workability of concrete fly ash of class-f by IS: 1727 (1967)/ IS: 3812-2 (2033) [20], [21] which was acquired from the Bathinda power plant in Punjab was used. Moreover, adding silica fumes increased the concrete’s strength and durability properties. Whereas superplasticizer used in this study was a new-generation poly-carboxylic ether-based admixture. This product is primarily designed for high-quality concrete applications requiring the highest levels of durability and performance. Fine Aggregate (FA) used is natural river sand that was taken from a river source located nearby. The sieve analysis test was completed as per IS: 2386-1 (1963) [22] requirements and the fine aggregate is complying with Zone-II as per IS: 383 (2016) [23] shown in fig 3. Crushed stones of size 12.5 mm size were used as natural coarse aggregate and the abandoned concrete served as the source for the recycled aggregate, which was then crushed, sieved, and mixed to achieve a gradation that was approximately comparable to that of the reference coarse aggregate. The particle size distribution curve of coarse aggregates is shown in fig 4. Physical properties of aggregates such as fineness modulus, specific gravity, water absorption, and crushing value as specified in IS: 2386-3 (1963) [24]are tabulated in Table3.

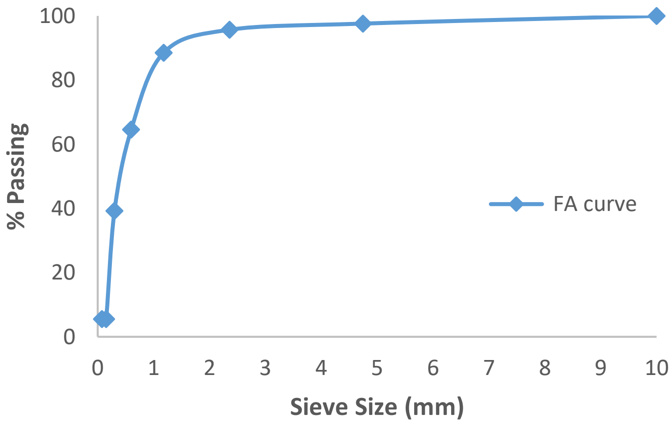

Figure 3. Sieve Size Analysis of fine Aggregate

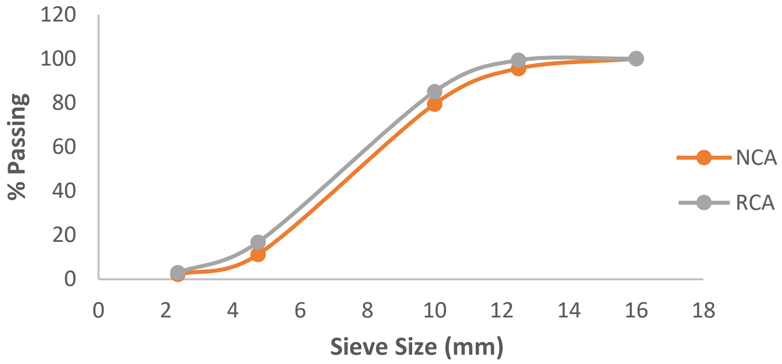

Figure 4. Sieve Size Analysis of Natural and Recycled Coarse

Table 1. Chemical properties of binders

Component %	Cement	Fly ash	Silica fumes
SiO_2	22	54	90
Cao	63	12	1
Al_2O_3	5	30	<1
Fe_2O_3	4	8	<1
MgO	1.5	1.9	<1
Loss on ignition	1	4	<1

Table 2. Physical and Mechanical properties of cement

Test name	Results
Physical properties	
Specific Gravity	3.15
Normal Consistency	31 %
Initial setting time	45 min
Final setting time	450 min
Compressive strength (MPa)	
7-days	34.5
28-days	45.6

Table 3. Physical properties of aggregates

Material	Nominal size (mm)	Fineness modulus	Specific gravity		Water absorption (%)	Crushing value (%)
			Apparent	Saturated		
FA	---	2.088	2.70	2.65	---	---
NCA	12.5	6.14	2.63	2.59	0.48	21
RCA	12.5	5.97	2.6	2.31	0.51	25

Mixture proportion

To achieve the target strength of 32 MPa, three series of SCC mixtures were meticulously designed under annexure-E of IS:10262[25]. A preliminary step of the research was conducted to evaluate the effect of thermally stimulated superplasticizer before adding recycled aggregate. However, the mixes in Series- I were also checked for other properties. The mixes defined in table 4 demonstrate that the concrete mixture in Series I comprises two mixes C1 and C2, both containing 100% NCA. A stimulated superplasticizer was added in C2 to assess the effect on the characteristics of fresh concrete and was compared with the former which contained normal SP. The water/powder (w/b) ratio was kept at 0.48 and 0.45 and the total binder concentration of 440kg/m^3 respectively for C1 and C2.

The mix proportions of Series II depicted in Table 4 consist of four combinations of concrete mix. Considering the advantages of using RCA as a replacement for aggregates the proportion was decided concerning the previous studies in the literature. CR0S0 (100% NCA) served as a control mix to assess the influence of blends containing RCA. In CR30S0, CR45S0, and CR60S0, or secondary mixes, NCA was replaced with RCA in ratios of 30%, 45%, and 60% by mass. The SP content and w/b ratio of 0.45 was kept the same as that of the C2 mix in Series- I for all four mixes in Series II. To minimize the undesirable effect of RCA, cement was partially replaced by fly ash by

30% keeping the total binder content at 440 kg/m^3. Series III comprises three tertiary mixes and were evaluated with slight changes in the proportions of different materials. However, silica fumes (SF) with a content of 30 kg/m3 i.e.,7% by weight of cement was a major additional material substituted. Meanwhile to keep the fresh properties under the standard values of EFNARC[26] and IS:10262 [25] the range of superplasticizers was kept between 4 - 4.5 kg/m3.

Table 4. Mix proportions.

Series	Mix ode	w/b	Content in Kg/m^3							
			Water	Cement	FA	SF	Aggregates			SP
							Fine	Coarse	RC	
I	C1	0.48	210	440	0	0	902	780	--	4
	C2	0.45	200				916			
II	CR0S0	0.45	200	310	130	--	868	780	--	4
	CR30S0						865	546	234	
	CR45S0						863	429	351	
	CR60S0						861	312	468	
III	CR30S7	0.45	200	300	110	30	853	546	234	4.5
	CR45S7						852	429	351	
	CR60S7						850	312	468	

Tests adopted for determining concrete properties.

Fresh concrete test

Tests such as Slump Flow & T50 cm, J- Ring, L-Box, V-funnel & V- funnel T5 were employed to analyse concrete’s fresh properties, such as viscosity, filling capacity, and passing-ability of concrete. All tests were conducted under the procedure and guidelines of EFNARC 2005.

Compression test

Three specimens were cast, and water cured to assess the compressive strength characteristics of each SCC mixture. Taking an average of the three specimens was recorded after a curing time of 7,14, 28, and 56 days. A crushing load was applied on 100 mm cubes at a rate of 140 kg /mm^2/min until the specimen failed. The test was done as per IS: 516- 1959 [27].

Splitting tensile test

A splitting tensile test was conducted to ascertain the tensile strength of concrete, commonly known as the load at which the concrete components may fracture. This method consists of applying the diametrical force along the length of the specimen which induces tensile stress (T) on the plane. The strength has been calculated using the formula i.e., $T = \frac{2P}{\pi DL}$ Where P is the compressive force in Newton (N), D and L are the diameter and length of the specimen, respectively. The average of the three cylindrical specimens with dimensions of 100 mm in diameter and 200 mm in length was utilized to gauge the split tensile strength. The test was conducted in compliance with the prescribed guidelines IS: 5816-1999 [28].

Water penetration test

The water penetration test of concrete has important implications in civil construction works that are envisioned to retain water or are in contact with water. This test was conducted as per IS: 516 (Part 2/Sec 1)- 2018 [29]. A concrete cube specimen of size 150 mm cured for 28 days was subjected to the hydrostatic pressure of 5kg/cm^2 for 72 hours from one side. Further, the cube was halved into parts, and water penetration depth to the nearest mm was measured with the help of a measuring scale.

Rapid chloride permeability test

The evaluation of concrete's ability to resist the ingress of chloride ions is commonly assessed using the Rapid Chloride Permeability Test (RCPT) as per ASTM C1202 standards. A voltage of 60 volts was set across the specimen for 6 hours. The total charge that passed through it was recorded at an interval of 30 minutes.

Method of Thermal Stimulation

The Superplasticizer was kept in a non-reactive bottle and caped to prevent evaporation of water, maintaining water-solid content as in its original state. The bottle was then kept in the water at the same temperature and was stimulated steadily to 50°C[10]. The stimulated SP was put in a heat chamber for 24 hours to keep it warm at 50°C.

Preparation of SCC mix

The RCA being porous in nature hence absorbs water from the mixes and therefore was brought to saturated surface dry (SSD) conditions prior to the mixing. To attain this RCA was kept in water for 24 hours thereupon maintaining the fresh property requirements of SCC mixes i.e., passing, filling, and flowability. The mixer was then filled with both the coarse and fine aggregates before being properly mixed for two minutes. Some amount of superplasticizer and water were subsequently added, and the mixture was again stirred for two minutes. In addition, binders were added till a homogeneous mixture was obtained. The remaining water and superplasticizer were incorporated into the matrix and given a thorough mix. Slump flow, T_{50cm}, V-funnel, and L-box tests were used to gauge the fresh characteristics of all the concrete mixtures. The molds were cast as per the requirements of mechanical and durable properties. After 24 hours of casting specimens were de-molded and water cured under standard conditions for 28 days.

Results and discussion

Effect of thermal stimulation

The findings from various research demonstrate that the use of SP, a type of comb-shaped PC copolymer with varying lengths of side chains that transform into a disordered coil structure when exposed to water, enhances the fluidity (Slump Flow) of the mixture[11], [12]. In Series I, of Table 5, mix C2 displays a 3% improvement in fluidity in comparison to the C1 mix due to the inclusion of thermally stimulated SP in the said mix, which causes the side chain's random coil structure to expand and increase in length [10], as illustrated in figure 5. This expansion provides more surface area for cement particles to bind to, leading to better dispersion and a higher water-reducing capacity for the SP. Consequently, trapped water is released, and more water is available in the concrete mixture to work with. This process reduces plastic shear stress and enhances the mix's rheology by increasing fluidity.

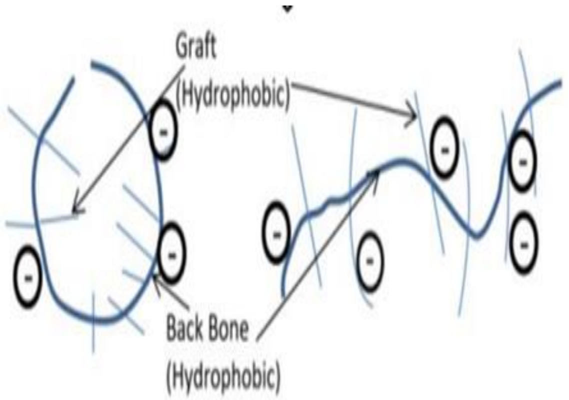

Figure 5. Effect of thermal stimulation.[12]

Fresh properties.

The results tabulated in Table 5 demonstrate the workability characteristics of SCC mixes. The tests which were conducted to determine the fresh properties of concrete were the slump flow test, T_{50} flow time test, V-funnel test, and L-box test.

Slump flow test results.

Figure 6 illustrates the Slump Flow test results for various SCC mixes in this experiment, which measure their filling ability and range from 610-670mm. According to the EFNARC guidelines, the results can be divided into two categories: SF1 and SF2. Mixes C1, C2, CR0S0, CR30S0, and CR30S7 had slump values below 650mm and are classified as SF1, while CR45S0, CR60S0, CR45S7, and CR60S7 had slump values above 650mm and are classified as SF2. The trend in Slump Flow results indicated an increase as the RCA content increased[14]. This tendency could be attributed to the aggregates being brought to SSD condition before mixing, which neutralizes the water absorption from the mix by RCA, subsequently improving flowability[30]. Additionally, the spherical particles of FA contributed to the ball-bearing effect, further enhancing flowability[6]. The mixes in Series III, which included SF, showed a similar trend due to its lower content. Moreover, the SP dosage was increased to counteract the resistance offered by SF and maintain the Slump Flow.

T_{50cm} flow time test results.

The T_{50cm} refers to the time that a mix takes to reach 50 cm in diameter on the flow table test. This test is related to the measure of the viscosity of the mixture. From Table 5, it is observed that all the mixes were in the VS2 category, which is in accordance with the EFNARC guidelines. The result shows that T_{50cm} flow time increases as the RCA content was increased. Which in a sense means that the higher content of RCA produces higher viscosity in mixes[31], [32]. This is credited to the characteristics of RCA i.e., rougher texture, porous nature, water absorption, and angularity [33], [34]. When SF was added to mixes, the flow time was identical to that of blends that do not contain SF at all RCA substitution levels reason being the same as given for slump flow.

V-funnel test results.

Test results of the V-funnel are shown in Table 5. This is also a viscosity test of mixes like T_{50cm}. The time taken by the mix to flow downward was measured, which classifies the viscosity of the mixes in various categories as classified by

EFNARC. The recorded flow time of all the SCC mixes of Series I and Series II lie in the VF2 category. This is due to the same cause discussed for T_{50cm}[32], [35]. However, the mix CR45S0 lies in the VF1 category which could be due to the optimized content of RCA used in the mix. With the incorporation of SF in tertiary mixes of Series III demonstrated a similar outcome, with no impact on the flow time owing to the controlled amount of SF in the mixture [2].

L-box test results.

L-box results are tabulated in Table 5. According to EFNARC, this test evaluates the SCC's appropriateness for usage in a structural member with congested reinforcement by measuring its passing ability. From table, it is evident that there is no prominent change in the L-box ratio of all the secondary and tertiary mixes in comparison to the controlled mix. All the mixes used in the study were classified under the PA2 category based on EFNARC standards. Moreover, the findings indicate that the addition of 7% SF did not have an impact on the L-box ratio. This was due to the presence of FA and the increased content of thermally stimulated SP, which facilitated a reduction in friction between the particles and incapacitated the potential adverse effects of SF on the concrete's fresh properties.

Table 5. Fresh property test results

Mix code	Slump flow (mm)	T50 cm flow time (s)	V-funnel flow time (s)	L-box passing ratio (H2/H1)
C1	610	2.6	9	0.90
C2	630	2.5	8.3	0.93
CR0S0	630	2.2	8	0.93
CR30S0	640	2.5	8.3	0.91
CR45S0	670	2.7	9	0.91
CR60S0	660	3	11.3	0.88
CR30S7	633	2.6	8.6	0.94
CR45S7	659	2.9	10	0.92
CR60S7	652	3.2	12.2	0.90

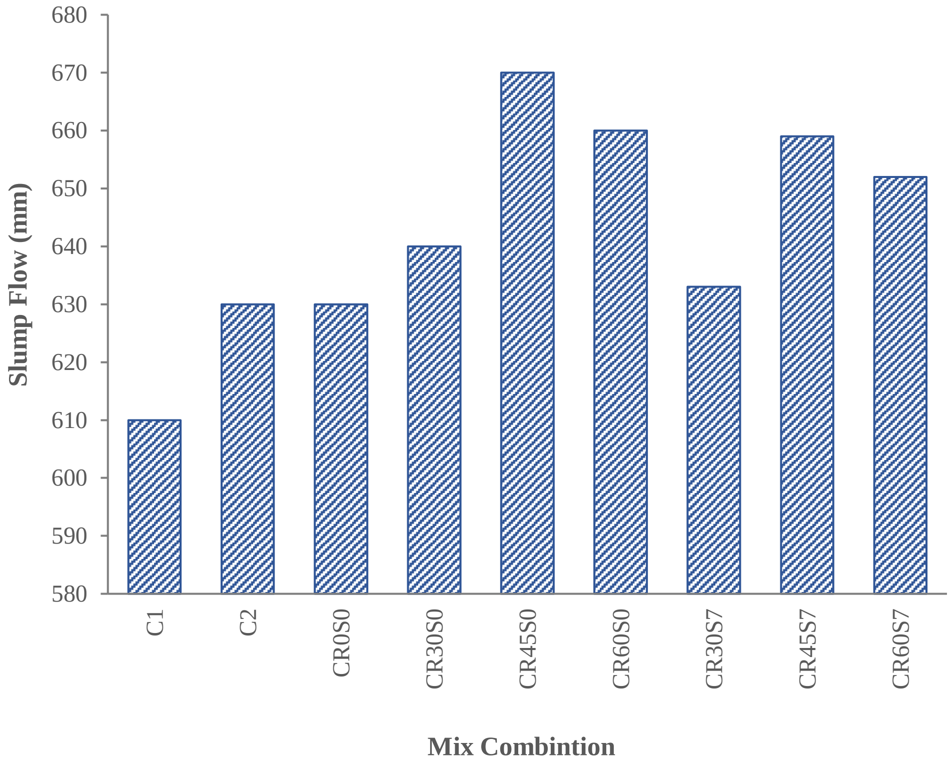

Figure 6. Slump flow

Strength properties.

Compressive strength results of SCC mixes having different amount of RCA is presented in Table 6. It is evident from the table that Series I mixes do not affect the strength of the concrete however the difference in the strength of the C1 and C2 mixes is due to the lower w/b ratio in the latter. A comparison between 7 days and 28 days of curing shows that the 7 days compressive strength was lesser than 28 days compressive strength. This is because the microstructure of concrete has not developed fully for a shorter period of curing. All the mixes achieved more than 62% of compressive strength at the 7 days in comparison to 28 days of curing.

In contrast to the control mix of 100% NCA (CR0S0), the results given below in fig 7 show that the mixes containing different percent of RCA (i.e., 30%,45%,60%) have shown higher early age strength (7 days) which is attributed to the rougher surface texture of RCA. Besides this better interlocking was noticed which may have counterbalanced the decrease in compressive strength due to inferior RCA[36]. Various studies have proposed that the attached mortar with RCA contains un-hydrated cement particles which hydrate to impart early strength[6]. A decline in the compressive strength of mixes (CR30S0, CR45S0, and CR60S0) was observed in late curing ages of (28 and 56 days) as that of the control mix (CR0S0) this might be due to various reasons like exhaustion of un-hydrated cement, weak interfacial transaction zone developed or weak adhered mortar[37], [38]. Furthermore, due to the optimization, CR45S0 has demonstrated superior strength characteristics when compared to two other mixes, CR30S0 and CR60S0. Specifically, the strength of CR45S0 was found to be 4% and 8% higher than CR30S0 and CR60S0, respectively, after 28 days of curing. In Series III SCC mixes prepared with silica fumes depicted a similar tendency. However, the introduction of this pozzolanic material has shown positive results, and the strength deficit compared to the control mix (CR0S0) was very less at the later stages of curing. The compressive strength increases by 5.6%, 3.5%, and 5.7% at 7 days, 14 days, and 28 days respectively for CR45S7 relative to the CR45S0 mix. The results indicate that the enhancement in strength was due to the formation of C-S-H (calcium silicate hydrate) gel and pore-filling ability due to the addition of silica fumes [2], [16].

The tensile splitting strength at 28 days is graphically illustrated in figure 8. From the graph, it is evident that the splitting tensile strength of the control (CR0S0) mix was the highest among all three Series of mixes. It was observed that mixes of Series-II i.e. CR30S0, CR45S0, and CR60S0 had 1.2%, 3.8%, and 5.3% lower splitting tensile strength than mixes CR30S7, CR45S7, and CR60S7 of Series-III. The difference in strength between the series was due to the addition of silica fumes in Series III mixes[15], [16]. Which subdue the inferior strength of the aggregate and the porous nature of RCA and exhibited positive results in Series III.

Table 6. The compression strength of mixtures.

Mix/ Test	Compression Test (MPa)			
	7 days	21 days	28 days	56 days
C1	19.7	28	31.4	33
C2	21	28.9	33.4	35.8
SR0S0	21.2	29.4	33.9	36.9
SR30S0	22	24.5	26.5	27.7
SR45S0	23.2	25.6	27.8	29.2
SR60S0	21.6	23.7	25.6	26.8
SR30S7	23.2	24.8	27.7	29.7
SR45S7	24.5	26.5	29.4	30.81
SR60S7	22.5	25.7	28.6	29

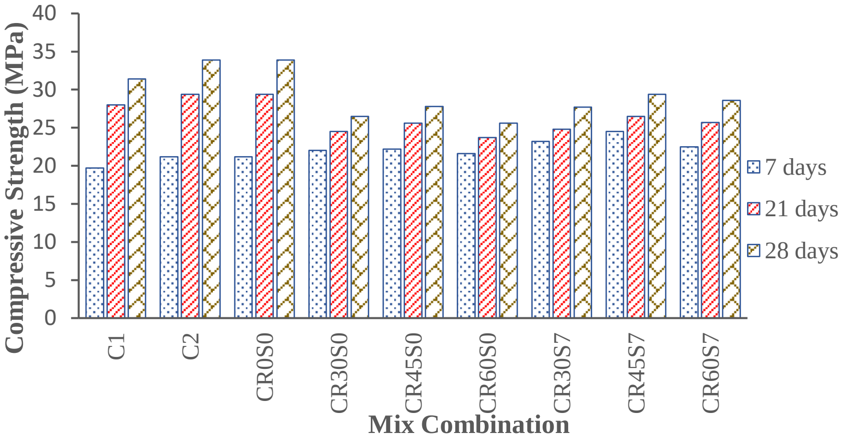

Figure 7. Compressive strength of mixes

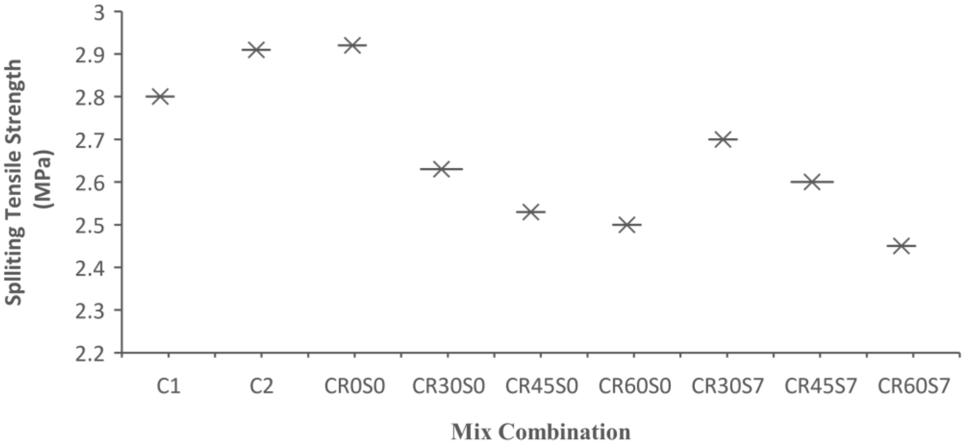

Figure 8. Splitting tensile Strength.

Durability properties.

Penetration test results.

The test results of SCC mixes are presented in figure 9. The water penetration results were recorded in the range of 2.5 cm to 3.2 cm. C2 had a lesser penetration depth than C1 because of the lower water-cement ratio. Quantitatively the secondary mixes of Series II show an increase in depth by 8%, 16%, and 28% concerning the controlled mix at 28 days of curing. This is due to the porous nature of RCA which allows it to absorb more water as compared to NCA[2], [39]. Furthermore, the presence of SF in mixes of Series III was found to be effective in redressing the adverse effects of RCA that were prominent in the mixes without SF as discussed earlier. The penetration depth in SCC mixes CR30S7, CR45S7, and CR60S7 was found to be 6%, 12%, and 20% less than the controlled mix, the reason being the fineness of SF in filling the voids[15], [40].

Chloride penetration test results.

The results obtained for RCPT are shown in figure 10. The resistance to chloride mitigation in concrete is accredited to the microstructure of the concrete and it also depends on the water-cement ratio. In this study, the chloride penetration test was conducted on C2, CR45S0, and CR45S7 mixes only. Since the RCPT test was done after 28 days the results which were feasible with the given criteria were chosen that is the mixes that had better results. The fig 10 shows that mix C2 had higher resistance to chloride ions in comparison to the other two mixes and was falling in the medium permeability category. Among the other two mixes, CR45S7 provided 30% better resistance to chloride ions. The improved microstructure is attributed to the use of pozzolanic material (i.e. fly ash and silica fume) Series III which increases resistance to chloride attack due to their pore-filling ability led to show resistance to the fast movement of ions[2], [41].

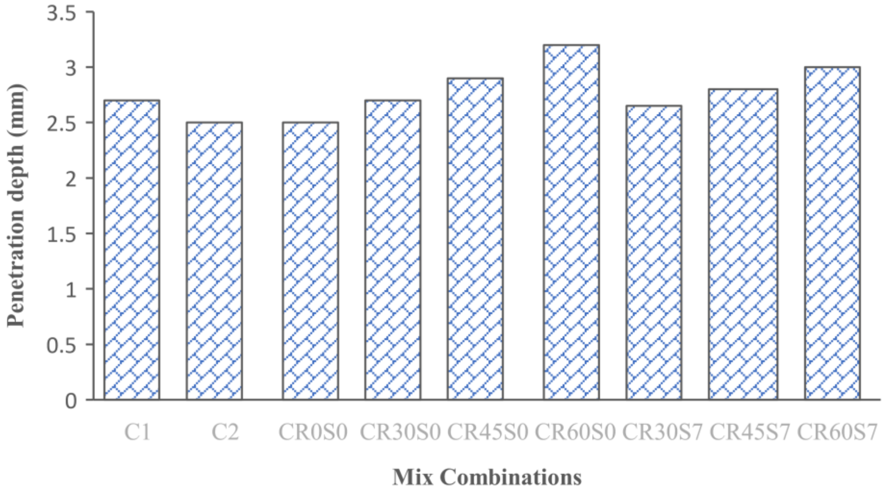

Figure 9. Penetration test results.

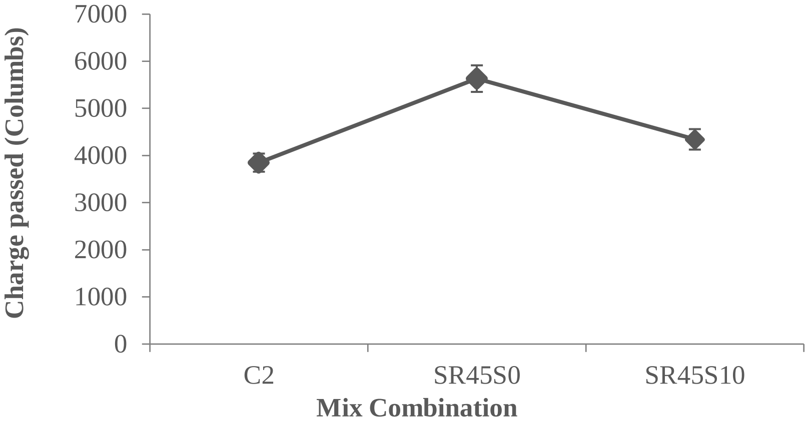

Figure 10. The test result of RCPT.

Conclusion

The study aimed to evaluate the feasibility of incorporating demolished concrete waste into Self-compacting concrete (SCC) as a means of reducing reliance on landfills, conserving natural aggregate resources, and promoting ecological equilibrium. The results of this investigation indicate that RCA could serve as a viable substitute for traditional materials, supporting the advancement of sustainable development practices.

The conclusions that can be drawn from this study are:

1. Applying thermal stimulation to admixture improves the fluidity of mortar and reduces the amount of admixture needed to achieve the same level of slump and fluidity as non-heated admixture. This reduction in the volume of admixture results in lowered production costs.
2. The fresh properties of concrete mixes showed an improvement in filling ability with an increase in recycled concrete aggregate (RCA) content. Whereas test results on mix viscosity indicated a significant increase in shear stresses, particularly for 60% of RCA mixes, due to the rough texture of RCA and its water absorption from the mix.
3. Concrete mixes containing 45% of the recycled concrete aggregate (RCA), specifically CR45S0 and CR45S7, demonstrated higher compressive strength compared to other mixes. This is due to the optimized content of RCA. However, an opposite trend was observed in terms of tensile strength, as an increase in RCA content did not result in improved strength in any mix.
4. From durability properties it was concluded that the porous structure of RCA had led to decreasing in chloride resistance which could be due to the lower grade of concrete used. Therefore, this grade of concrete should be avoided in areas that are prone to acid attacks.
5. The inclusion of silica fumes as binder material has demonstrated significant advantages in all evaluations of concrete mixes. To manage the reduction in fluidity due to SF, the volume of the Superplasticizer (SP) can be adjusted, or its impact can be estimated by simulating the behaviour of mixes at other temperatures of SP

such as 40°C, and 60°C.

6. Overall, the findings of this study, along with those from previous research, provide compelling evidence that recycled concrete aggregate (RCA) is a practical and effective material for producing highly workable concrete with minimal or no negative impact on its properties in both fresh and hardened states. Moreover, the Self-compacting concrete (SCC) produced using RCA could be utilized in numerous civil engineering projects that necessitate moderate strength.

Acknowledgments

We would like to express our gratitude to the team at the Material Testing Laboratory, School of Civil Engineering, LPU, Phagwara, India, for their valuable assistance during the experimentation work presented in this paper. Their support was instrumental in the successful completion of this research.

REFERENCES

1. 'Centre for Science and Environment'. https://www.cseindia.org/india-manages-to-recover-and-recycle-only- about-1-per-cent-of-its-construction-and-demolition (accessed Mar. 31, 2023).
2. K. Kapoor, S. P. Singh, and B. Singh, 'Permeability of self-compacting concrete made with recycled concrete aggregates and Portland cement-fly ash-silica fume binder', *J Sustain Cem Based Mater*, vol. 10, no. 4, pp. 213–239, 2020, doi: 10.1080/21650373. 2020. 1809029.
3. F. M. Khalaf and A. S. Devenny, 'Recycling of Demolished Masonry Rubble as Coarse Aggregate in Concrete: Review', doi: 10. 1061/ASCE0899-1561200416:4331.
4. M. Safiuddin, U. J. Alengaram, M. A. Salam, M. Z. Jumaat, F. F. Jaafar, and H. B. Saad, 'Properties of high-workability concrete with recycled concrete aggregate', *Materials Research*, vol. 14, no. 2, pp. 248–255, 2011, doi: 10.1590/S1516-14392011005000039.
5. A. Rao, K. N. Jha, and S. Misra, 'Use of aggregates from recycled construction and demolition waste in concrete', *Resour Conserv Recycl*, vol. 50, no. 1, pp. 71–81, Mar. 2007, doi: 10.1016/ j. resconrec. 2006. 05.010.
6. S. C. Kou and C. S. Poon, 'Properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates', *Cem Concr Compos*, vol. 31, no. 9, pp. 622–627, Oct. 2009, doi: 10.1016/ j. cemconcomp. 2009.06.005.
7. S. Santos, P. R. da Silva, and J. de Brito, 'Self-compacting concrete with recycled aggregates – A literature review', *Journal of Building Engineering*, vol. 22. Elsevier Ltd, pp. 349–371, Mar. 01, 2019. doi: 10 1016/ j.jobe. 2019. 01.001.
8. S. A. Santos, P. R. da Silva, and J. de Brito, 'Mechanical performance evaluation of self-compacting concrete with fine and coarse recycled aggregates from the precast industry', *Materials*, vol. 10, no. 8, Aug. 2017, doi: 10.3390/ma10080904.
9. K. Devi, P. Aggarwal, and B. Saini, 'Admixtures Used in Self-Compacting Concrete: A Review', *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, vol. 44, no. 2, pp. 377–403, Jun. 2020, doi: 10.1007/s40996-019-00244-4.
10. M. S. Salehi, Z. Tahery, S. Sasaki, and S. Date, 'Effect of Thermal Stimulation of Admixture to Workability of the Mortar', *International Journal of Engineering and Technology*, vol. 9, no. 3, pp. 183–188, 2017, doi: 10.7763/ IJET.2017.V9.967.
11. M. Takigawa, Y. Bomura, S. Hashimoto, and S. Date, 'Effect of Thermal Stimulation on Various Characteristics of Superplasticizer', *International Journal of Engineering and Technology*, pp. 262–266, Aug. 2019, doi: 10. 7763/IJET.2019.V11.1158.
12. G. Gelardi and R. J. Flatt, 'Working mechanisms of water reducers and superplasticizers', in *Science and Technology of Concrete Admixtures*, Elsevier, 2016, pp. 257–278. doi: 10.1016/B978-0-08-100693-1.00011-4.
13. 'Superplasticizer'. Superplasticizer. (2023, January 30). In Wikipedia. https:// en. wikipedia. org/ wiki/ Superplasticizer
14. M. Tuyan, A. Mardani-Aghabaglou, and K. Ramyar, 'Freeze-thaw resistance, mechanical and transport properties of self-consolidating concrete incorporating coarse recycled concrete aggregate', *Mater Des*, vol. 53, pp. 983–991, 2014, doi: 10.1016/ j.matdes. 2013. 07.100.
15. A. M. Falmata, A. Sulaiman, R. N. Mohamed, and A. U. Shettima, 'Mechanical properties of self-compacting high-performance concrete with fly ash and silica fume', *SN Appl Sci*, vol. 2, no. 1, p. 33, Jan. 2020, doi: 10.1007/s42452-019-1746-z.
16. L. Lam, Y. L. Wong, and C. S. Poon, 'Effect of Fly Ash and Silica Fume on Compressive and Fracture Behaviors of Concrete', *Cem Concr Res*, vol. 28, no. 2, pp. 271–283, Feb. 1998, doi: 10.1016/S0008-8846 (97)00269-X.

17. B. of Indian Standards, 'IS 4031-4 (1988): Methods of physical tests for hydraulic cement, Part 4: Determination of consistency of standard cement paste'.
18. B. of Indian Standards, 'IS 4031-5 (1988): Methods of physical tests for hydraulic cement, Part 5: Determination of initial and final setting times'.
19. B. of Indian Standards, 'IS 4031-6 (1988): Methods of physical tests for hydraulic cement, Part 6: Determination of compressive strength of hydraulic cement (other than masonry cement)'.
20. B. of Indian Standards, 'IS 1727 (1967): Methods of test for pozzolanic materials', 1968.
21. B. of Indian Standards, 'IS 3812-2 (2033): Specification for Pulverized Fuel Ash, Part 2: For Use as Admixture in Cement Mortar and Concrete', 2013.
22. B. of Indian Standards, 'IS 2386-1 (1963): Methods of Test for Aggregates for Concrete, Part I: Particle Size and Shape'.
23. I. Standard, M. Bhavan, B. Shah, and Z. Marg, 'Coarse and Fine Aggregate for Concrete - Specification', 2016. Accessed: Mar. 22, 2023. [Online]. Available: www.bis.org.in www.standardsbis.in
24. B. of Indian Standards, 'IS 2386-3 (1963): Methods of test for aggregates for concrete, Part 3: Specific gravity, density, voids, absorption and bulking'.
25. I. Standard, 'Concrete Mix Proportioning — Guidelines', 2019. Accessed: Mar. 22, 2023. [Online]. Available: www.standardsbis.in
26. 'The European Guidelines for Self-Compacting Concrete Specification, Production and Use "The European Guidelines for Self Compacting Concrete"', 2005. [Online]. Available: www.efnarc.org
27. B. of Indian Standards, 'IS 516 (1959): Method of Tests for Strength of Concrete'.
28. B. of Indian Standards, 'IS 5816 (1999): SPLITTING TENSILE STRENGTH OF CONCRETE - METHOD OF TEST'.
29. B. of Indian Standards, 'IS 516 (Part 2/Sec 1) : 2018 Hardened Concrete — Methods of Test', 2018. [Online]. Available: www. Standards bis.in
30. P. O. , & M. V. M. Modani, 'Self-compacting concrete with recycled aggregate: A solution for sustainable development.', *International Journal of Civil and Structural Engineering, 4, 430-440.*, vol. 4, pp. 430–440, 2014.
31. W. C. Tang, P. C. Ryan, H. Z. Cui, and W. Liao, 'Properties of Self-Compacting Concrete with Recycled Coarse Aggregate', *Advances in Materials Science and Engineering*, vol. 2016, 2016, doi: 10. 1155/ 2016/ 2761294.
32. J. Hu, Z. Wang, and Y. Kim, 'Feasibility study of using fine recycled concrete aggregate in producing self-consolidation concrete', *J Sustain Cem Based Mater*, vol. 2, no. 1, pp. 20–34, Mar. 2013, doi: 10. 1080/ 21650 373. 2012.757832.
33. E. Güneyisi, M. Gesoglu, Z. Algin, and H. Yazici, 'Rheological and fresh properties of self-compacting concretes containing coarse and fine recycled concrete aggregates', *Constr Build Mater*, vol. 113, pp. 622–630, Jun. 2016, doi: 10.1016/j.conbuildmat.2016.03.073.
34. W. Tang, M. Khavarian, A. Yousefi, and H. Cui, 'Properties of self-compacting concrete with recycled concrete aggregates', in *Self-Compacting Concrete: Materials, Properties and Applications*, Elsevier Inc., 2019, pp. 219–248. doi: 10.1016/B978-0-12-817369-5.00009-X.
35. Y. P.C. and T. D.C.L, 'Utilisation of Recycled Aggregate as Coarse Aggregate in Concrete', *Journal of Civil Engineering, Science and Technology*, vol. 1, no. 1, pp. 1–6, Aug. 2009, doi: 10.33736/jcest.60.2009.
36. M. Gesoglu, E. Güneyisi, H. Ö. Öz, I. Taha, and M. T. Yasemin, 'Failure characteristics of self-compacting concretes made with recycled aggregates', *Constr Build Mater*, vol. 98, pp. 334–344, Nov. 2015, doi: 10. 1016/ j. conbuildmat.2015.08.036.
37. K. C. Panda and P. K. Bal, 'Properties of self compacting concrete using recycled coarse aggregate', in *Procedia Engineering*, Elsevier Ltd, 2013, pp. 159–164. doi: 10.1016/ j. proeng.2013.01.023.
38. Z. J. Grdic, G. A. Toplicic-Curcic, I. M. Despotovic, and N. S. Ristic, 'Properties of self-compacting concrete prepared with coarse recycled concrete aggregate', *Constr Build Mater*, vol. 24, no. 7, pp. 1129–1133, Jul. 2010, doi: 10.1016/ j. conbuildmat. 2009. 12. 029.
39. S. K. Kirthika and S. K. Singh, 'Durability studies on recycled fine aggregate concrete', *Constr Build Mater*, vol. 250, p. 118850, Jul. 2020, doi: 10.1016/ j. conbuildmat. 2020. 118850.
40. C. Lu, H. Yang, and G. Mei, 'Relationship between slump flow and rheological properties of self compacting concrete with silica fume and its permeability', *Constr Build Mater*, vol. 75, pp. 157–162, Jan. 2015, doi: 10.1016/j.conbuildmat.2014.08.038.

41. N. Singh and S. P. Singh, ‘Carbonation resistance and microstructural analysis of Low and High Volume Fly Ash Self Compacting Concrete containing Recycled Concrete Aggregates’, *Constr Build Mater*, vol. 127, pp. 828–842, Nov. 2016, doi: 10.1016/ j. conbuildmat.2016.10.067.