An Experimental Study on Enhancing Recycled Aggregate Concrete Properties Through Silica Fume Incorporation

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Research Article

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Abstract

Construction and demolition waste and shortage of natural resources is growing issue that has been arisen through recent years all over the world. Although concrete, the most adaptable construction material, is a key factor in the expansion of the industrial and infrastructural sectors, it has been argued that concrete is not an environmentally friendly material because of its destructive resource-consumption nature and the potential for serious environmental impact after its use. However, it will continue to be the dominant building material utilised on a global scale. The present study aimed to assess the concrete properties with the effect of silica fume and recycled aggregates with the design mix of M30 grade of concrete. The study aimed to investigate the effects of replacing natural coarse aggregates with various percentages of recycled concrete aggregates (10%, 20%, 30%, 40%, and 50%) and using silica fume (2.5% and 5%) as a substitute for cement in the production of concrete. To achieve this, different concrete mixes were prepared and tested for their compressive strength, split tensile strength, and flexural strength, while also conducting a rapid chloride permeability test to determine the chloride ion penetration. The results showed that using recycled aggregates up to 20% can optimize compressive and tensile strength, while flexural strength can be optimized up to 30%. The use of recycled aggregates in concrete production can help reducing the consumption of natural resources and incorporating silica fume as a cement alternative can help reduce the environmental impact of cement production upto5%.

Introduction

Industrialization is essential for developing nations like India, and it is crucial for promoting economic development and self-sufficiency. However, industrialisation has led to a very high pace of urbanisation growth in India, which has also had major negative effects on the environment. Rapid infrastructure development necessitates a large amount of building supplies, as well as the necessary location and land. Construction and demolition waste (C& D), by-products from industry, and other non-traditional sources are being considered due to the rising demand for building materials, including coarse aggregates, sand, and cement. To reduce material demand and environmental degradation caused by waste disposal, efforts must be made to convert undesirable C&DW and industrial wastes into usable raw materials for a variety of useful purposes. Investigations were carried out to address the challenges and achieve a high proportion of RA in concrete. Studies have shown that recycled aggregates possess certain properties such as a high-water absorption rate, high porosity, low density, and low specific gravity (Narud, 1983). When recycled aggregate is used to replace natural aggregate, concrete tends to lose its density, compressive strength, modulus of elasticity, and durability as per multiple studies (Cong Kou et al., 2007). However, there are certain mixing techniques such as the double mixing method and the two-stage mix approach method that can be employed to improve the qualities of recycled aggregate concrete (Otsuki et al., 2003). Both methods aim to strengthen the interfacial zone around the recycled aggregate by filling up some of the pores and cracks in the cement slurry. These methods share similar concepts and can be used to enhance the overall performance of recycled aggregate concrete. As a result, recycled aggregate concrete is produced that is denser and has greater strength and durability. When pozzolanic chemicals are included, concrete made with recycled aggregate performs better in terms of strength and durability.

One way to increase the compressive strength of recycled aggregate concrete is by using ground fly ash and ground rice-husk bark as reinforcement (Tangchirapat et al., 2008). Construction waste must be stored, managed, and turned into expensive recycled aggregate (RA) before it can be used in building (Dilbas & Çakır, 2020). Because RAC contains two different types of interfacial transition zones—one between the RCA and the fresh mortar and another between the recycled aggregates concrete and the existing mortar—its microstructure is much more complex than that of conventional concrete. As a result of its high porosity and numerous microcracks that were created during RCA production, the ancient mortar is the weakest component of the RCA, and its strength is equivalent to the maximum allowable for concrete strength. Concrete strength grows in tandem with the bond ss between the aggregate and mortar. In contrast to high strength concrete, which fails through the new interfacial transition zone (ITZ), recycled aggregate concrete is fragile than Natural Aggregate (NA) concrete and fails through the aggregates themselves, including the previous ITZ. Because recovered aggregates typically contain between 30 and 35 percent and 65 to 70 percent by volume of previous cement paste, the presence of adhering mortar is considerable. To improve the qualities of RCA, it is essential to develop a treatment method that can remove the adhering mortar at a level that minimises the adverse consequences. While fly ash and micro silica are utilized to enhance the durability of concrete, they also have a minor negative impact on its mechanical properties. Fly ash can help make RAC more manageable by decreasing its permeability. Silica fume enhances the microstructure of concrete by producing a denser matrix due to its tiny size and vast surface area (Dimitriou et al., 2018).

The goal of this study is to ascertain whether a concrete mixture design that includes mineral admixtures as partial replacements for cement and RCA as a replacement for NA may reach an adequate performance for structural applications. RCA are given a treatment procedure to lessen the amount of mortar that has adhered to them and enhance their qualities. Moreover. The economic features of the RCA are as important to the mechanical and durability characteristics, and a comparison of natural aggregates and RCA is provided. The potential environmental and financial advantages might enhance the public's perception of RCA and increase its use.

Materials

Locally available ordinary Portland cement of Grade 43 was used in this experimental study. The cement had a specific gravity of 3.13, an initial setting time of 189 minutes, and a final setting time of 356 minutes. Grade 92D silica fume with a relative density of 2.1 was also utilized. The chemical properties of the cement and silica fume are listed in table 1 and 2 respectively. For this study, locally available natural coarse aggregates of nominal size 20mm and fine aggregates of zone II were employed. Recycled concrete aggregates were procured from a concrete structure's demolition site. Mechanical processes were then used to remove the adhered mortar on the recycled aggregates. These processes involved hammering the recycled aggregate to break it into smaller pieces and later using a wire brush to remove the attached mortar. After crushing, a 20mm sieve was used to pass the recycled aggregates, ensuring that they were of a similar size to the natural aggregates. The physical properties of the coarse natural and recycled aggregate can be found in table 3.

Table 1: Chemical properties of cement OPC grade 43 and Silica fume

Chemical properties	Cement	Silica Fume
SiO_2	23.21	2.6
$AL_2 O_3$	4.94	0.8
FE_2O_3	3.7	4.9
CAO	63.2	3.4
MgO	2.5	1.2
SO_3	2.6	-
K_2O	0.7	-
loss of ignition	0.65	3

Table 2: Physical Properties of OPC and Silica Fume

Physical Properties	Cement	Silica Fume
Specific Gravity	3.13	2.1
Initial Setting	189 Min	-
Final Setting	356 Min	-
Soundness	0.4MM	-
fineness	94.50%	93

Table 3: Physical properties of natural and recycled aggregates

Properties	Natural Aggregates		Recycled Aggregates
	Fine Aggregates	Coarse Aggregates	Coarse Recycled Aggregate
Specific gravity	2.73	2.85	5.2
Water absorption	0.82	0.75	6.5
Fines modulus	3.06	6.2	6.45

Experimental Methodology

Specimen Casting and Curing

For this experimental study, a total of 18 different types of concrete mixes were prepared in the laboratory. These mixes had varying percentages of recycled aggregates, ranging from 0% to 50%, which were replaced with natural coarse aggregate. Additionally, different percentages of silica fume were used to replace cement, ranging from 0% to 5%. The mix ratios of all 18 mixes are given in table number 4. To evaluate the strength and durability properties of these concrete mixes, several types of specimens were cast, including 150mm diameter and 300mm length cylinders for tensile strength, 150x150x150 mm cubes for compressive strength, 5cm length and 10mm diameter discs for rapid chloride penetration test, and beams of size (10cm x 10cm x 50cm) for flexural strength. The specimens were cured in a water tank for 7 and 28 days before testing. A consistent water/binder ratio of 0.45 was employed in all concrete combinations, and the initial slump of the concrete mixtures was maintained between 50 to 100.

Table.4 Mix Proportions of concrete mix designs

S. No	Mix Designation	W/C Ratio	Cement	FA	CA	RA(KG)	SILCAFUME
1	RA0SF0	0.45	704	586.66	1163.55	0	0
2	RA10SF0	0.45	704	586.66	1047.23	116.35	0
3	RA20SF0	0.45	704	586.66	930.85	232.70	0
4	RA30SF0	0.45	704	586.66	814.50	349.05	0
5	RA40SF0	0.45	704	586.66	698.15	465.40	0
6	RA50SF0	0.45	704	586.66	581.80	581.75	0
7	RA0SF2.5	0.45	686.4	586.66	1163.55	0	17.6
8	RA10SF2.5	0.45	686.4	586.66	1047.23	116.35	17.6
9	RA20SF2.5	0.45	686.4	586.66	930.85	232.70	17.6
10	RA30SF2.5	0.45	686.4	586.66	814.50	349.05	17.6
11	RA40SF2.5	0.45	686.4	586.66	698.15	465.40	17.6
12	RA50S.F2.5	0.45	686.4	586.66	581.80	581.75	17.6
13	RA0S.F5	0.45	668.8	586.66	1163.55	0	35.2
14	RA10SF5	0.45	668.8	586.66	1047.23	116.35	35.2
15	RA20SF5	0.45	668.8	586.66	930.85	232.70	35.2
16	RA30SF5	0.45	668.8	586.66	814.50	349.05	35.2
17	RA40SF5	0.45	668.8	586.66	698.15	465.40	35.2
18	RA50SF5	0.45	668.8	586.66	581.80	581.75	35.2

Tests

Compressive, Tensile and Flexural

In this experimental study, the compressive strength and flexural strength tests were performed in accordance with IS 516-1959, while the tensile strength test was performed in accordance with IS 516-1958. The compressive, flexural, and tensile splitting strengths of the concrete mixes were determined using a compression machine with a loading capacity of 3000 KN and 1000 KN. The compression and tensile splitting strength tests were conducted at a loading rate of 1.2 kN/s, while the flexural strength tests were conducted at a loading rate of 0.6 kN/s. The concrete specimens were evaluated at 7 and 28 days after curing in water.

Rapid Chloride Penetration Test

The Rapid Chloride Permeability Test (RCPT) is a standard method used to evaluate the resistance of concrete to the penetration of chloride ions, following the ASTM C1202 guidelines. The test is commonly used to assess the durability of concrete structures by measuring the rate of chloride ion penetration into the concrete. The RCPT involves subjecting a concrete disc specimen to an electrical field and measuring the amount of electrical charge that passes through the concrete. A higher amount of electrical charge passing through the concrete indicates a higher rate of chloride ion penetration. The test solution used for this test contains 12 grams of sodium hydroxide and 30 grams of NaCl after a 28-day duration.

Results And Discussion

Compressive Test

The aim of the experimental study was to explore the impact of using coarse recycled aggregates and silica fume on the compressive strength of concrete. The natural aggregates were replaced with coarse recycled aggregates in varying percentages ranging from 0 to 50%, while cement was substituted with silica fume in percentages ranging from 0 to 5%. The strength of concrete was evaluated by conducting compressive strength tests on concrete specimens of different mixes. The results of the tests revealed that the compressive strength of the concrete decreased as the percentage of recycled aggregates increased. However, the addition of silica fume to the concrete mix resulted in an increase in compressive strength, and the optimal percentage of recycled aggregates was determined to be 20%, as demonstrated in figure 8 and 9 below.

Tensile Strength

In this experimental investigation, the effect of coarse recycled aggregates and silica fume on the strength of concrete is examined with varying percentages of recycled aggregates ranging from 0 to 50%, along with silica fume ranging from 0 to 5%. The split tensile strengths were conducted on the different concrete mixes to check the effect of these replacements on the strength of concrete at 7 and 28 days, as listed below in figure 12 and 13. The test results showed that there was a great increase in the tensile strength of concrete with the addition of silica fume. During the experimental investigation, it was found that (5%) silica fume has a significant effect on the tensile strength of concrete at 7 and 28 days and also found that 20% replacement of recycled aggregates were the optimum.

Flexural Strength

In this current experimental investigation, the natural coarse aggregates are replaced with recycled concrete aggregates with varying percentages (10, 20, 30, 40, 50), and cement is replaced with silica fume with varying percentages ranging from 0% to 5%. The results indicated that the flexural strength of the concrete increased with the increase in the percentage of silica fume, even with higher percentages of recycled aggregates. However, the test results also showed that there was a sudden decrease in the flexural strength after 30% of recycled aggregates, and the optimum percentage of recycled aggregates was found to be 30%. The test was carried out using the code IS:516-1959, and the variations in the results are depicted in the graph below (Figure 16 and 17).

Rapid Chloride Penetration Test

The RCPT is commonly used to assess the durability of concrete structures, particularly in marine or coastal environments where exposure to chloride ions can cause concrete deterioration. The test results can provide an indication of the likelihood of corrosion in the reinforcing steel and can help determine the service life of the structure. The 28-day results indicate that silica fume decreased the penetrability of chloride ions in recycled aggregate concrete material, and mixtures formed with modified recycled concrete aggregates can be categorised as having very normal penetrability of chloride ions according to ASTM C1202

Conclusion

Aggregates constitute a significant percentage of concrete and have a significant impact on the physical properties of concrete mixtures. On the one hand, there are fewer natural resources available, but on the other, there is an increase in the volume of construction waste, which is seriously degrading the environment. Recycling demolition trash into recycled aggregates solves the problem of the scarcity of natural aggregates as well as maximising the use of construction waste. The goal of this study was to improve the RAC characteristics by substituting different amounts of recycled materials. Following conclusion can be drawn from the current study.

1. The replacement of natural aggregates with recycled aggregates leads to a reduction in the compressive strength of recycled aggregate concrete (RAC). However, incorporating silica fume into RAC presents a viable option for enhancing its compressive strength, thus enabling its use in structural applications. To optimize the compressive strength of RAC, 2.5% and 5% of silica fume can be added to the mixture. This finding indicates that it is feasible to utilize recycled aggregates as a substitute for natural aggregates in concrete while maintaining adequate compressive strength. natural aggregates being replaced with recycled aggregates, the RAC's compressive strength is reduced.
2. Using recycled aggregates alone, without any supplementary materials, leads to a reduction in compressive strength. Replacing 30% of aggregates results in a decline of 23% at 7 and 23.9% at 28 days, while replacing 50% leads to a higher loss of strength of 37.7% at 7 and 38% at 28 days.

Supplementary materials are necessary to maintain adequate strength levels when incorporating recycled aggregates in concrete.

3. The incorporation of silica fume in recycled aggregate concrete resulted in an improvement in compressive strength. Silica fume was used to replace cement at levels of 2.5% and 5%. Adding 2.5% silica fume and 0% recycled aggregate led to a 3% increase in compressive strength at 7 days and 3.5% at 28 days. Similarly, the addition of 50% recycled aggregate resulted in an increase of 1.30% at 7 days and 1.28% at 28 days. Using 5% silica fume and 0% recycled aggregate increased compressive strength by 4.9% at 7 days and 5% at 28 days. Meanwhile, a 50% recycled aggregate substitution, along with 5% silica fume, led to a 1.29% increase in compressive strength at 7 days and 2.94% at 28 days.
4. When recycled aggregate is utilised without any mineral admixture or other supplemental materials, the tensile strength decreases. When 30% of the aggregates are replaced, there is a decline of 25.5% at 7 days and 25% at 28 days, whereas 50% of the aggregates are replaced, there is a higher loss of strength of 35.04% at 7 days and 37% at 28 days.
5. Incorporating silica fume into recycled aggregate concrete helped to regain some of the lost strength. Silica fume replaced cement at levels of 2.5% and 5%. The addition of 2.5% silica fume and 0% recycled aggregate resulted in a 3.22% increase in tensile strength at 7 days and 3.34% at 28 days. When 50% recycled aggregate was used, there was a rise of 1.29% at 7 days and 0.84% at 28 days. Meanwhile, adding 5% silica fume and 0% recycled aggregate increased tensile strength by 5% at 7 days and 6% at 28 days. Utilizing 50% recycled aggregate with 5% silica fume led to an increase of 0.64% at 7 days and 0.83% at 28 days. These results suggest that incorporating silica fume can help to improve the tensile strength of recycled aggregate concrete.
6. When recycled aggregate is utilised without any mineral admixture or other additives, the flexural strength decreases. When 30% of the aggregates are replaced, the strength decreases by 15.10% after 7 days and by 25% after 28 days, but when 50% of the aggregates are replaced, there is greater loss in the strength decreases by 48% after 7 days and by 49% after 28 days.
7. Using silica fume significantly improves the resistance to chlorine attack at all replacement levels.
8. The study has shown the benefits of using silica fume as an extra cementitious material in recycled aggregate concrete as comparison to using silica fume as a replacement for cement.
9. The 28-day results indicate that silica fume decreased the penetrability of chloride ions in recycled aggregate concrete material, and mixtures formed with silica fume recycled aggregates concretes can be categorised as having very normal penetrability of chloride ions according to ASTM C1202.

Declarations

Compliance with Ethical Standards

The research paper by Shakir Nazir, a civil engineer, and assisted by Akshat Mahajan and Sahil Jaggi, assistant professors, confirms that the study was conducted in compliance with ethical guidelines set forth by the relevant ethics committee or regulatory body. They obtained informed consent from human subjects, maintained their privacy and confidentiality, and did not engage in any unethical practices.

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Figures

Figure 1

Recycled Aggregates used in experimental study

Figure 2

Coarse Aggregates used in experimental study.

Figure 3

Slump test (Before)

Figure 4

Slump test (After)

Figure 5

Casting of specimen

Figure 6

Curing of specimen.

Figure 7

Testing of concrete cube specimen for compressive strength

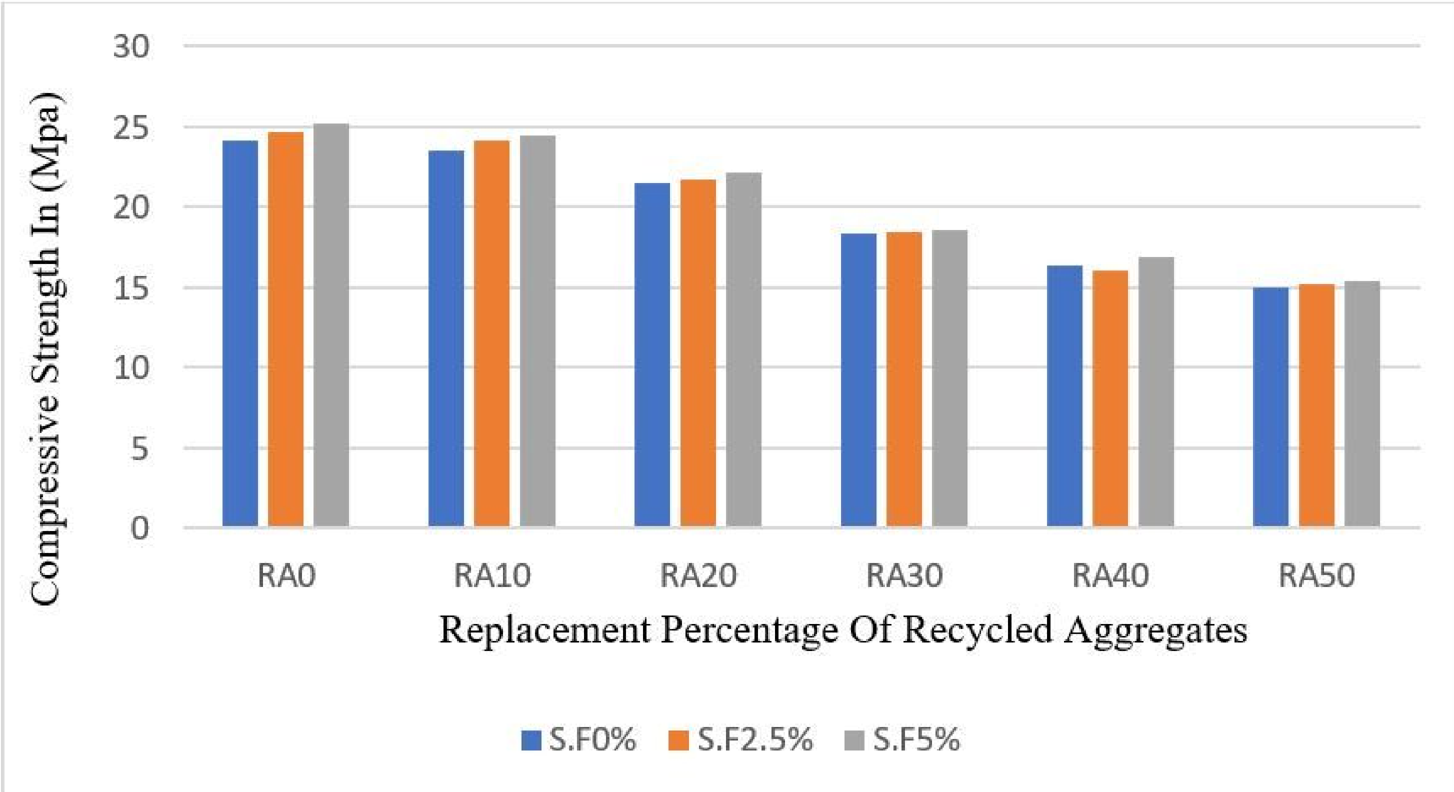

Figure 8

Variation of compressive strength with replacement percentage of recycled aggregates at 7 days

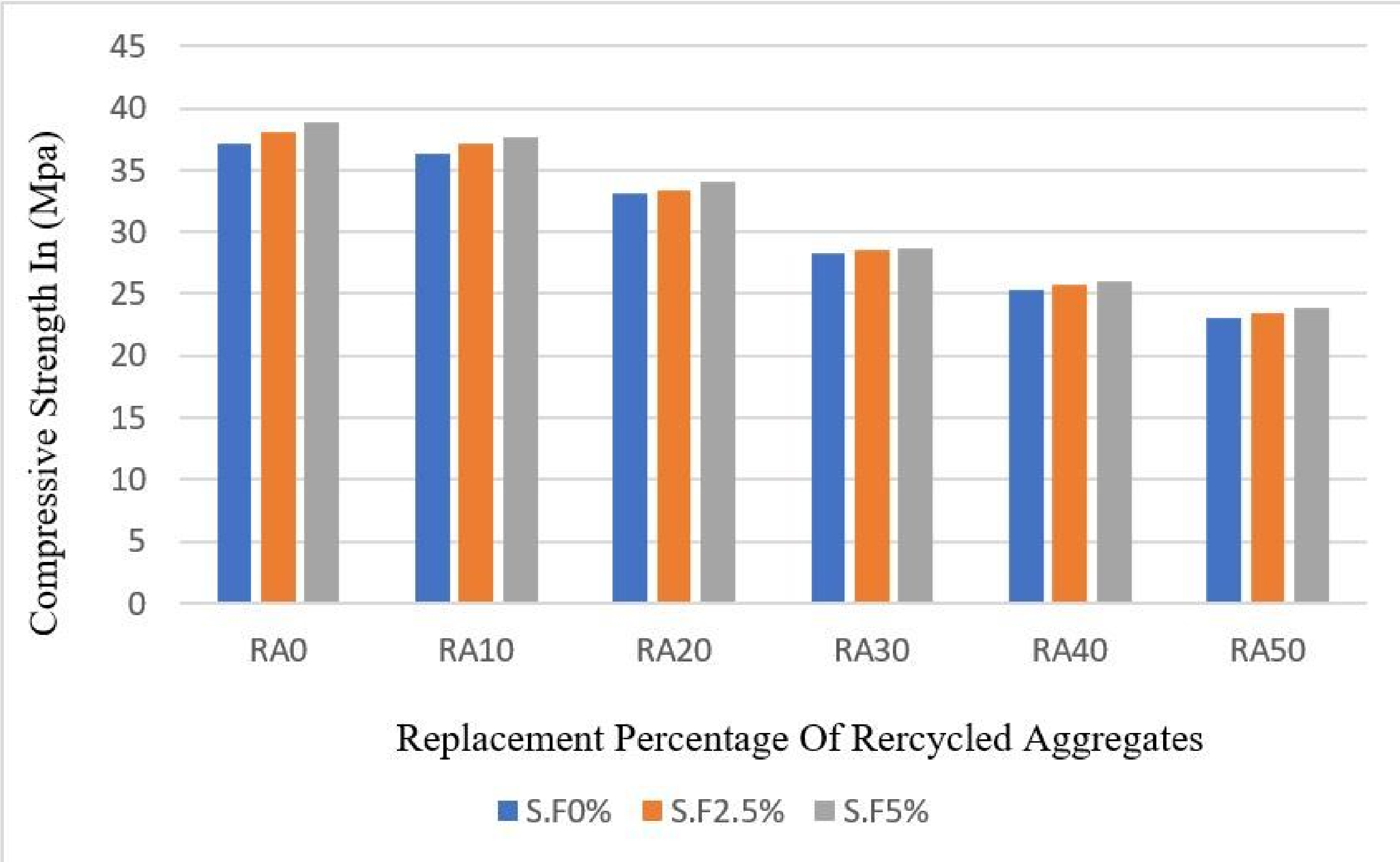

Figure 9

Variation of compressive strength with replacement percentage of recycled aggregates at 28 days

Figure 10

Testing of concrete cube specimen for tensile strength

Figure 11

Testing of concrete cube specimen for tensile strength

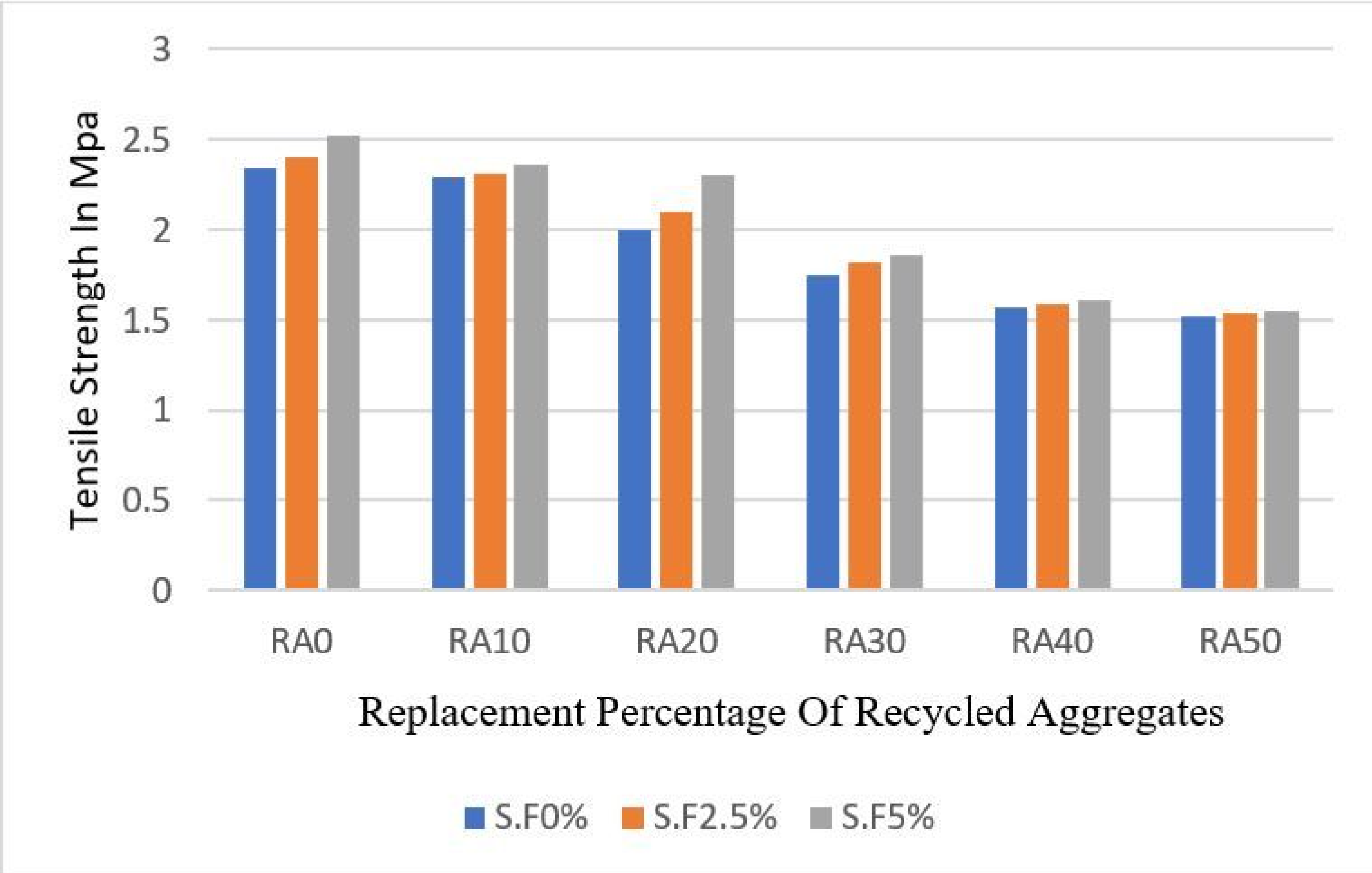

Figure 12

Variation of tensile strength with replacement percentage of recycled aggregates at 7 days

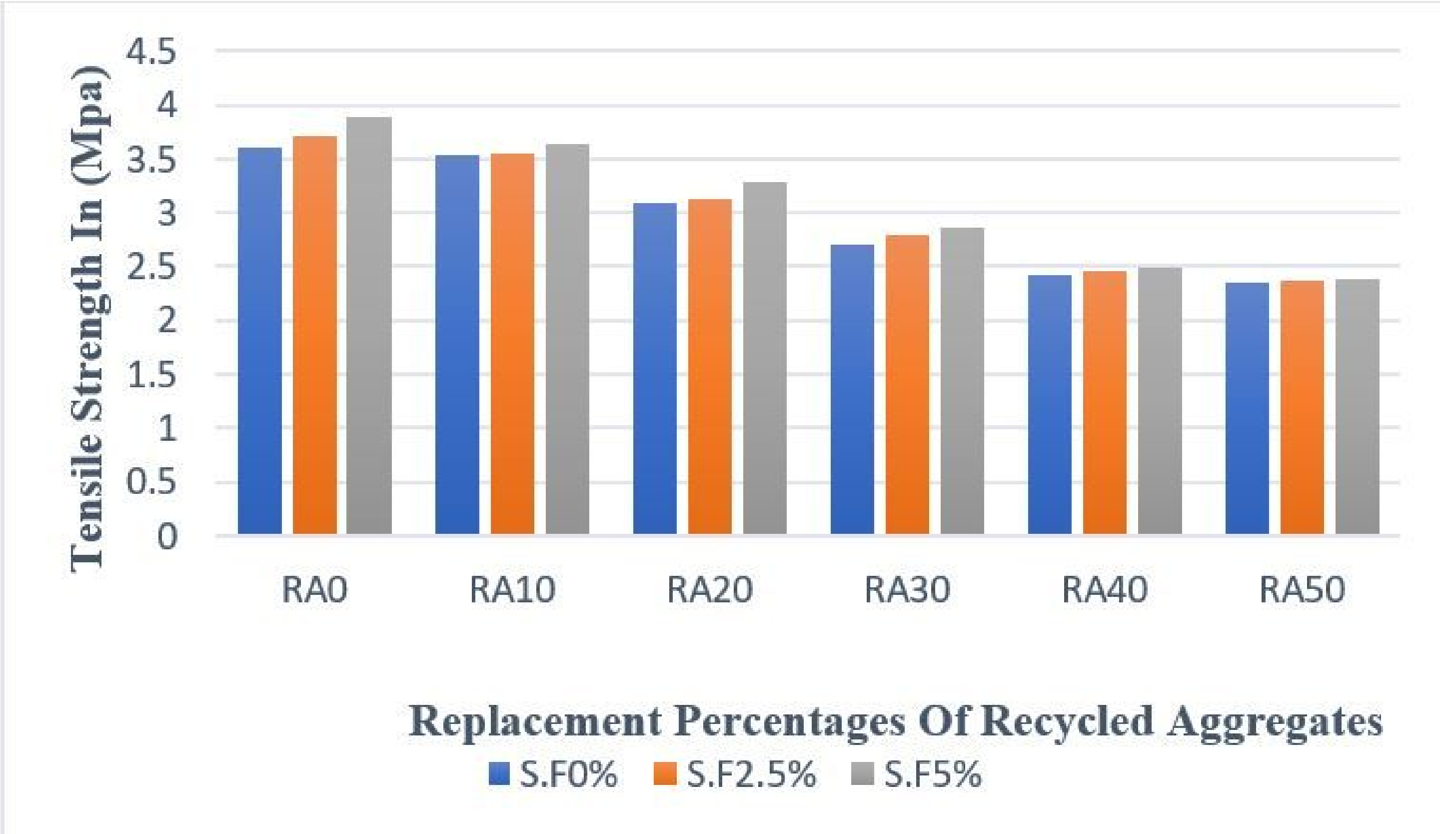

Figure 13

Variation of tensile strength with replacement percentage of recycled aggregates at 28 days

Figure 14

Testing of concrete beam specimen for flexural strength

Figure 15

Testing of concrete beam for flexural strength

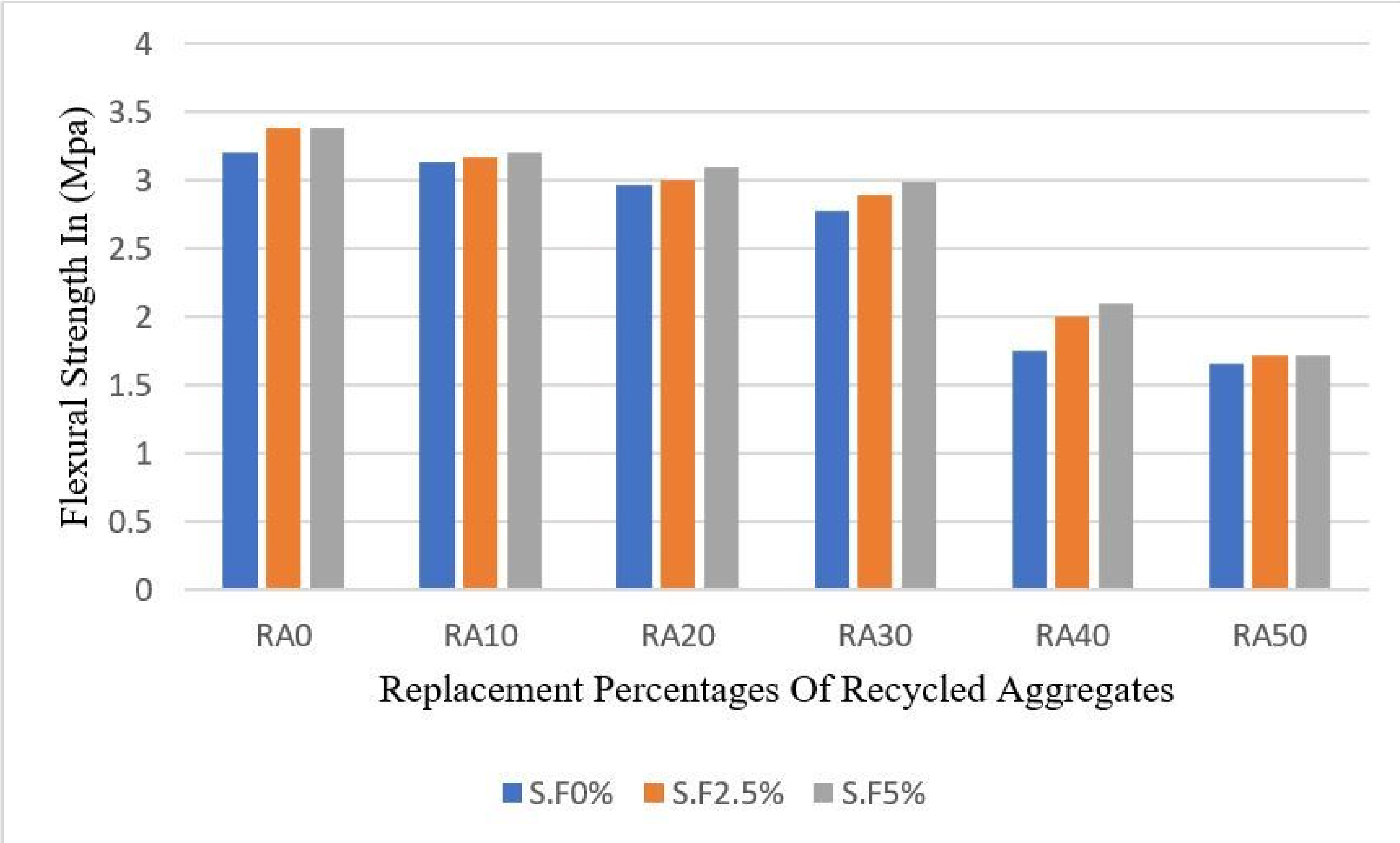

Figure 16

Variation of flexural strength with replacement percentages of recycled aggregates at 7 days

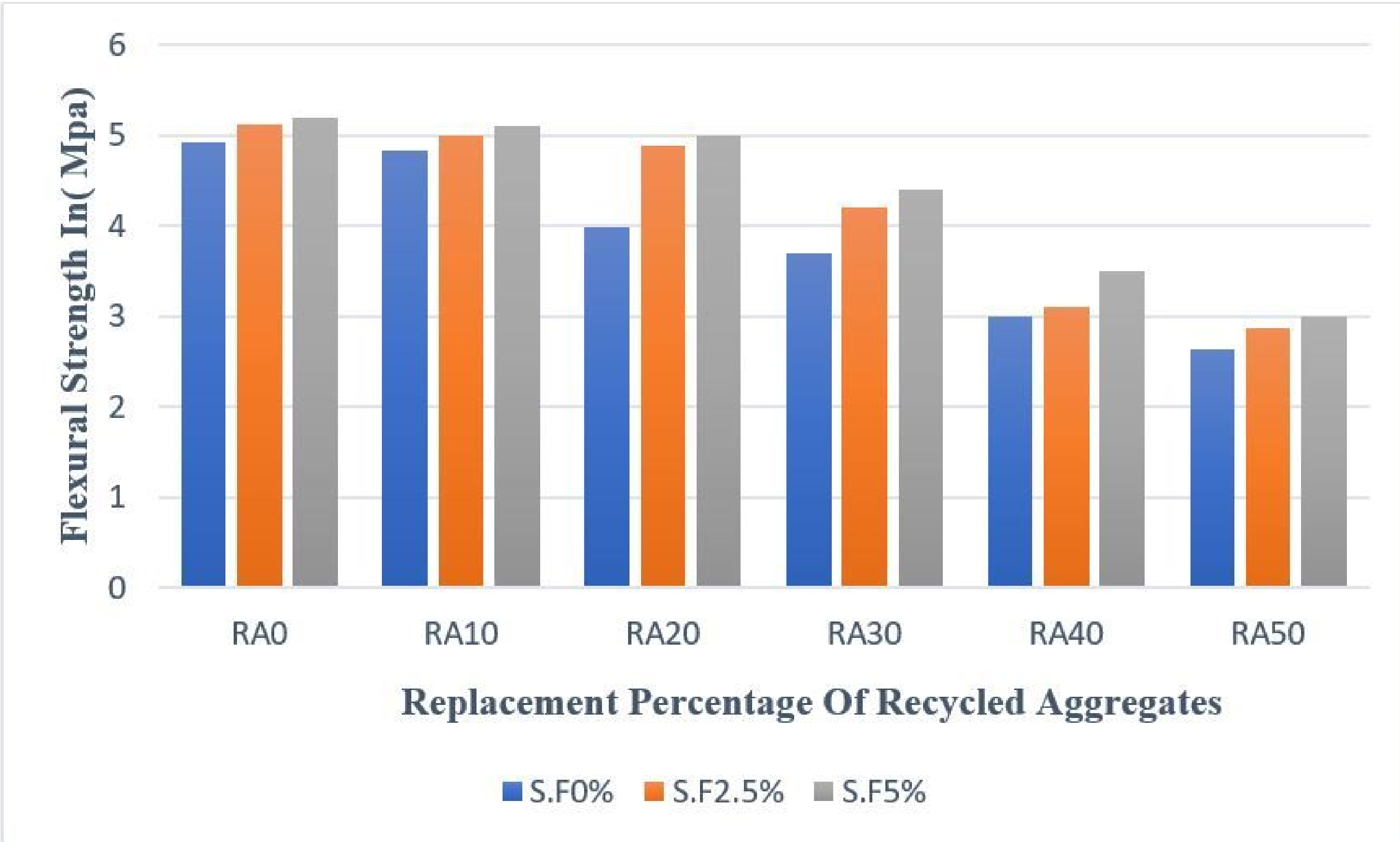

Figure 17

Variation of flexural strength with replacement percentages of recycled aggregates at 28 days

Figure 18

preparation of specimen

Figure 19

testing of specimen

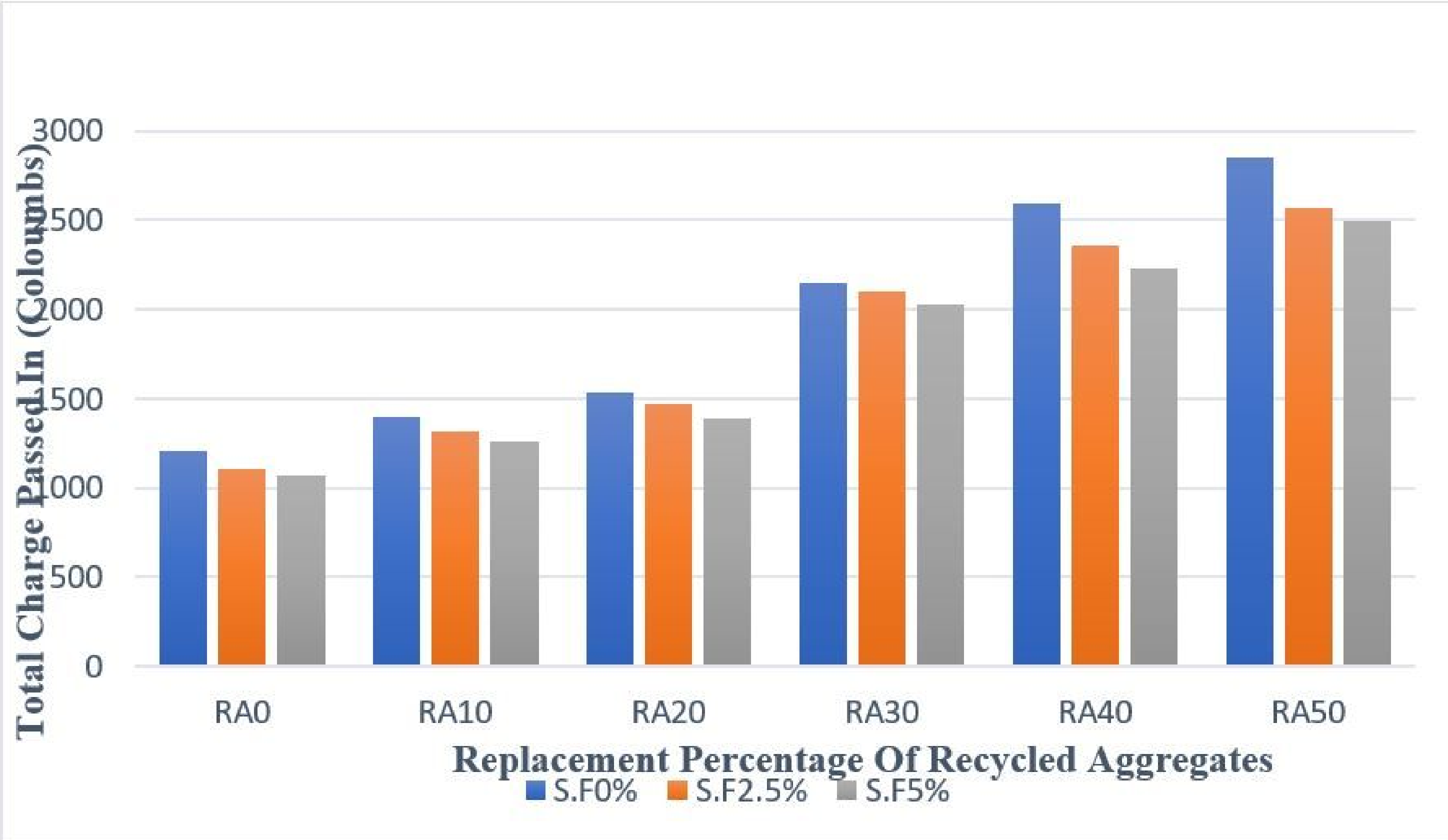

Figure 20

Variation of rapid chloride penetration test with the replacement of recycled aggregates at 28 days