Characteristics of Green Concrete with Industrial Wastes as Replacement of Fine and Coarse Aggregate

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Abstract. Waste generated due to various industrial activities are dumped as landfill posing serious environmental complications. Pollution control due to industrial waste has become one of concern across the globe. This study discusses foundry sand and coconut shell, two byproducts of the manufacturing and agriculture sectors. The most efficient use of these components is to include them into the concrete itself, either as a partial substitute for fine aggregate or coarse aggregate, or both. Durability tests were conducted on concrete samples with the replacement percentages determined to be optimal on the basis of mechanical characteristics. According to the findings, foundry sand may be utilised as a fine aggregate replacement in concrete, while coconut shell can be used as a coarse aggregate replacement without impacting its strength or durability.

1 Introduction

Concrete is an inert homogeneous structural material with versatile properties. Except for cement, the concrete's primary ingredients—fine aggregate, coarse aggregate, and water—come from the earth. Using up the world's limited natural resources to construct nations' essential infrastructure is an issue for all nations today. The researchers have experimented with different types of alternatives for the natural ingredients in the concrete. Fine aggregate is replaced with a variety of industrial waste such as Manufactured sand, Slag sand, sawdust, Powdered glass, groundnut shell, Fly ash, Quarry dust, oyster shell. In a similar way, coarse aggregate can be replaced with recycled coarse aggregate, E-waste, plastic waste, coconut shell, quarry dust. The utilisation of industrial waste in concrete provides dual advantages such as reduction in environmental pollution due to dumping of waste material and reduction in utilization of natural resources in concrete. The above advantages lead to sustainable development in the construction industry [1-3].

India is expected to have the second highest metal casting production in the world, at 11.2 million tonnes. When the molten metal is placed into the right mould, it solidifies into the desired form and size. Sand's heat conductivity and high silica content make it ideal for use in the casting and moulding processes used in metal foundries. To cast 1 tonne of metal, need around 4 to 5 tonnes of foundry sand. The sand is recycled and reused within the foundry two or three times before being deposited as waste foundry sand at a landfill. Indian foundry operations generate around 1.71 million tonnes [4-8] of foundry sand waste each year. Instead of being disposed of in a landfill, discarded foundry sand may be repurposed to make asphalt and cement, bricks, and geotechnical projects.

Coconuts are mostly farmed for their culinary value, but they have several additional applications. After Indonesia and the Philippines, India is the world's third biggest producer of coconuts. India is the world's biggest producer of coconuts and coconut products, so it's no surprise that the nation generates a significant amount of solid waste in the form of coconut shells, which may be used as activated carbon if burned to very high temperatures [911].

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Coconut shells make up a major amount of the waste that ends up in landfills in rural areas where rubbish collection is less regular. Coconut shells are less biodegradable and hence take up more space in landfills.

Jaya prithika and Sekar (2016) investigated the mechanical properties of concrete made using coconut shell as coarse aggregate, manufactured sand as fine aggregate, and granulated blast furnace slag as a cement replacement. Several curing processes, including water, steam, and conceal curing, were used to evaluate mechanical properties (compressive strength, flexural strength, static modulus of elasticity, Poisson's ratio, and fracture toughness). The mechanical properties of CS concrete treated with water were shown to be better when compared to steam curing and concealed curing. Joshua et al. (2018) summarized the results of using coconut shell ash as cement replacement (0 – 25% with increment of 5%). To verify the suitability, compressive strength at 7/28 days, XRF to evaluate pozzolanic activity was done. Prasath Kumar et al. (2019) replaced the normal concrete with coconut shell by 100%. The quality of concrete in terms of strength decreased for coconut shell concrete [12-16]. With the aim of improving the strength of CS concrete, authors have incorporated GGBS (0 – 20% with increment of 5%) for cement replacement to improve the pozzolanic activity. 10% GGBS incorporation is found to be the optimum percentage as there is an increase in strength by 15% and taken for durability tests and microstructure tests. The increase in strength for 10% GGBS was due to formation of C-S-H and C-A-S-H gel which was identified through micro structure study. Soumya et al. (2019) casted two sets of manhole cover slab with normal and coconut shell aggregate of size 600 × 600 × 100 mm with two different diameters (10 mm and 12 mm) of reinforcement. The slabs were tested for its workability, density, settlement, cracking load, ultimate load as prescribed by IS 12592: 2002. The CS concrete was 18.22% less dense than normal concrete [17-20]. The mix was designed for M30 grade of concrete, in which normal and CS concrete have achieved 40.33 and 35.16 N/mm^2 respectively. Test results confirmed that coconut shell aggregate can be used for manhole cover slab as per the codal provisions.

Manoharan Thiruvenkitam et al. (2020) assessed the strength and durability of concrete with 0 to 25 wt% of foundry sand for M30 grade concrete. Better durability properties were shown by mixes with waste foundry sand. Optimum replacement was 20 wt% foundry sand with similar properties as that of normal concrete and also reduces the cost by 12. 08 $ per m^3. Anuj Parashar et al. (2020) explored the use of WFS in self-compacting concrete with different replacement levels (0 to 40%) through workability, strength and durability properties along with microstructure study. The tests were performed at different ages and showed that 10% replacement with foundry sand is the optimum percentage of replacement without any degradation of strength. Aliakbar Gholampour et al. (2020) prepared concrete with a combination of foundry sand and recycled fine aggregate. The strength results along with elastic modulus reveal that foundry sand can be used up to 25% for replacing fine aggregate in concrete with increased workability and lesser water absorption. L.F. dos Santos et al. (2021) manufactured interlocking concrete pavement blocks in cylinder and hexagonal shape by replacing entire fine aggregate with foundry sand [21-25]. Tests such as compression, slump, water absorption, void ratio and microstructure analysis were performed to check the suitability of foundry sand in concrete. Less than 6% of water absorption and 35 MPa compressive strength makes the concrete blocks suitable for light traffic. Total replacement with foundry sand for natural river sand is suitable for hexagonal shaped blocks.

According to the research, no one has used foundry sand and coconut shells in concrete previously. The effects of using foundry sand FS as a partial substitute for fine aggregate FA and coconut shell CS as a partial replacement for coarse aggregate CA on the corrosion behaviour of concrete are explored.

2 Materials Used

The whole test was conducted using Ordinary Portland Cement (OPC) of grade 53. Coarse aggregates, ranging in size from 12 to 20 millimetres, are sourced from nearby stone crushers. As a fine aggregate FA, we used locally sourced river sand that was analysed in accordance with IS 2386: 1963 and found to meet the requirements of IS 383: 2016. The whole probe used regular drinking water. Coconut shells were acquired from a local Chennai market and utilised to partially replace coarse aggregate. In order to meet the requirements, the shells were broken. Everything that was large enough to go through a 12.5 mm screen was considered coarse aggregate. The M20 grade concrete mix was developed using IS 10262:2009. Table 1 displays the mix proportions used in the investigation, which were water to cement in the ratio of 0.5:1. Compressive strength, split tensile strength, and flexural strength have all been previously documented for concrete with the following mix proportions.

Table 1. Quantity of materials used for different mixes.

Mix code	% Replacement		Coarse aggregate	Fine aggregate	CS	FS
	CS	FS	kg/m³	kg/m³	kg/m³	kg/m³
CC	-	-	1245	662	0	0
M11	10	15	1120.5	562.7	124.5	99.3
M12	10	20	1120.5	529.6	124.5	132.4
M13	10	25	1120.5	496.5	124.5	165.5
M14	10	30	1120.5	463.4	124.5	198.6
M21	15	15	1058.25	562.7	186.75	99.3
M22	15	20	1058.25	529.6	186.75	132.4
M23	15	25	1058.25	496.5	186.75	165.5
M24	15	30	1058.25	463.4	186.75	198.6

3 Experimental Methods

Concrete with foundry sand FS as a partial replacement for fine aggregate FA and coconut shell CS as a partial replacement for coarse aggregate CA was tested for corrosion and durability using the Accelerated Corrosion Test (ACT), the Rapid Chloride Permeability Test (RCPT), and the acid resistance test.

3.1 Accelerated Corrosion test ACT

Casting a cylindrical piece with a 100 mm diameter and a 200 mm length, using an 8 mm steel bar embedded to a depth of 150 mm, provided the samples. The specimens were placed in a solution in a sodium chloride (3% NaCl) solution upto a depth of 180 mm. A constant voltage of 2V was applied between anode (reinforcement bar) and cathode (stainless steel plate) as shown in figure 1. A graph is plotted between the current applied and the elapsed time as shown in figure 2. The Chloride Penetration Time (CPT) is the time at which the first set of chlorides ions reach the reinforcing bar.

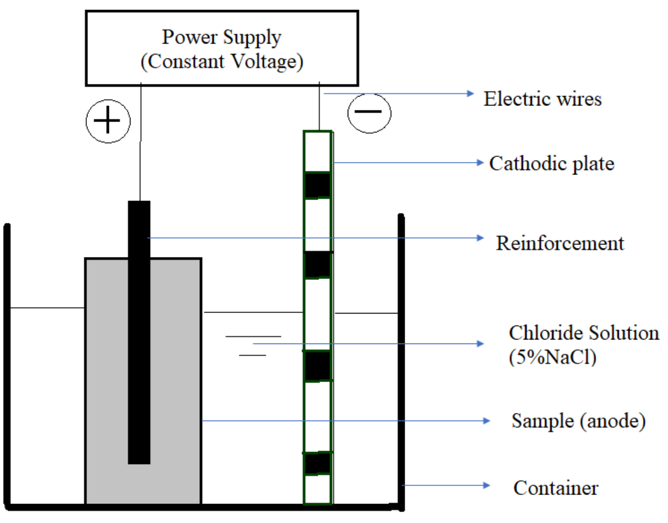

Fig. 1. ACT test setup.

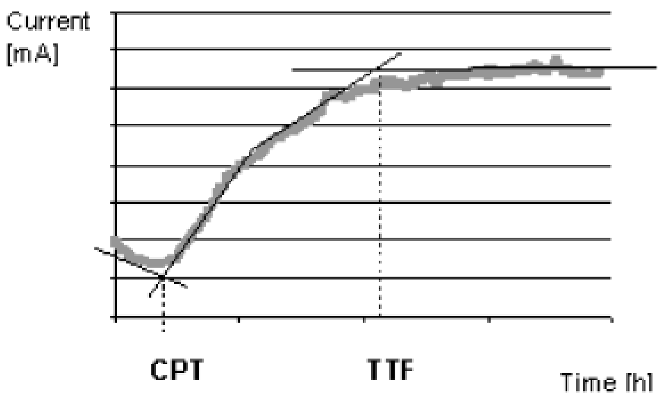

Fig. 2. Graphical representation of CPT

3.2 Test for Permeability to Chloride, Rapid (RCPT)

The Rapid Chloride Permeability Test (RCPT) was performed in accordance with ASTM C1202 to determine the permeability of concrete to chloride ions. The casting process took 28 days, during which time the material cured in a cylinder-shaped mould measuring 100 mm in diameter and 200 mm in length. Using a concrete saw, a 50-millimetre-long core was extracted from the cylinder-shaped specimen. A vacuum chamber was used to cure the epoxy on the 100 mm in diameter by 50 mm in length sample. Figure 3 shows the sample being loaded into the RCPT machine. Both sides of the specimen are submerged in a 3% NaCl and 0.3N NaOH solution in the test cell. The data recorder takes measurements every 30 minutes for 6 hours while a potential difference of 60 V is applied. After 6 hours, the sample was taken out of the cell. In Table 2, we compare the total charge in Coulombs by looking at how each value affects the concrete's resistance. The permeability of the concrete affects how quickly chloride ions may diffuse throughout the material.

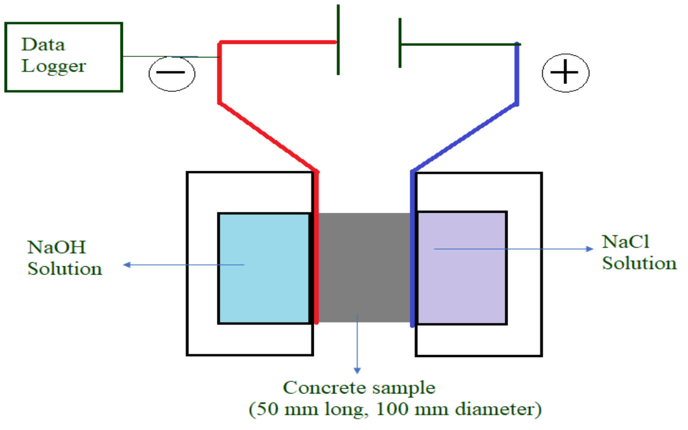

Fig.3. RCPT test apparatus.

3.3 Resistance to acid

After cubes had been hydrated for 28 days, they were put through an acid resistance test. A sulfuric acid solution with a pH of 0.3 was made by adding 5% sulphuric acid to water by volume. After recording their initial weight (WI), the cured samples were stored in the diluted solution for 60 days at a constant pH of 0.3. The specimens were brought out the solution and splashed in running water and dried for a period of 24 hours to measure final weight (W_F) and also tested for its compressive strength. The resistance to acid penetration was measured in terms of percentage weight loss and residual compressive strength.

$$\text{Percentage of weight loss} = \frac{w_I - w_F}{w_I} \text{ x } 100$$

4 Results and Discussion

4.1 Test for accelerated corrosion

The Chloride Penetration Time (CPT) is determined via an accelerated corrosion test to determine how long it takes for chloride ions to initiate corrosion. Table 2 and Figure 4 show the findings, making it clear that, as CPT time in hours grows, so does the replacement level of coarse and fine aggregate. The increase in CPT time indicates that the concrete is less prone to corrosion. However, the CPT time of M22 is similar to the conventional concrete and mix M14 has more CPT which means that it is more durable than CC. There is a decreasing trend in CPT hrs for the mixes M21 – M24 with 15% coconut shell which indicates that increasing the coconut shell above 15% may increase the probability of corrosion.

Table 2. CPT of CS – FS Concrete.

Mix	% Replacement		CPT (hrs)
	CS	FS	
CC	-	-	17.3
M11	10	15	17.8
M12	10	20	18.1
M13	10	25	18.6
M14	10	30	19.2
M21	15	15	18.5
M22	15	20	17.9
M23	15	25	17.5
M24	15	30	17

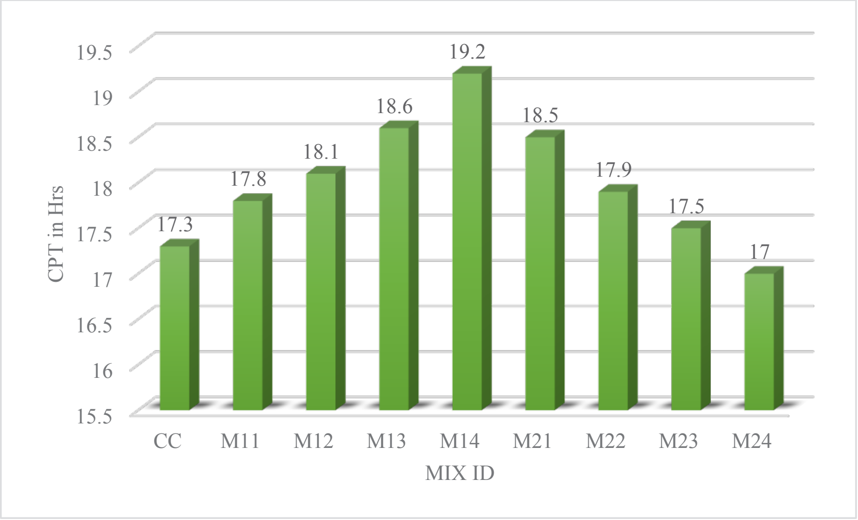

Fig. 4. CPT of CS – FS Concrete.

Penetration Test for Chloride in a Hurry To determine how easily chloride ions may corrode concrete, the RCPT Rapid Chloride Penetration Test is performed. Table 3 and Figure 5 display the experimental findings in terms of charge passing through the concrete in Coulombs. Permeability values are categorised as extremely low permeability, low permeability, moderate permeability, and high permeability according to the ASTM standard for RCPT. From the results, it is clear that all the CS-FS mixes along with CC fall under the low permeability category of ASTM C102. In comparison with CC, mix M22 with 15% CS and 20% FS have similar charge-passed values in Coulombs.

Table 3. Chloride penetration of CS – FS Concrete.

Mix	% Replacement		Charge passed (Coulombs)	Permeability
	CS	FS		
CC	-	-	1622	Low
M11	10	15	1566	Low
M12	10	20	1532	Low
M13	10	25	1511	Low
M14	10	30	1477	Low
M21	15	15	1528	Low
M22	15	20	1609	Low
M23	15	25	1588	Low
M24	15	30	1555	Low

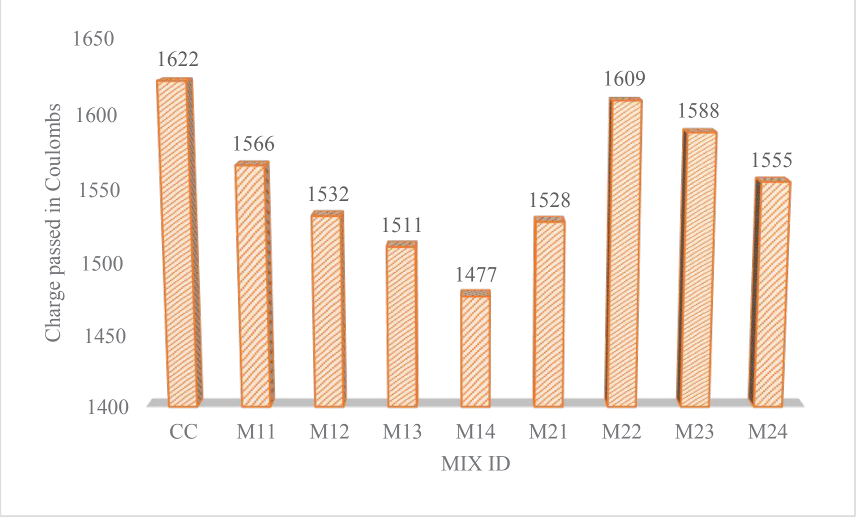

Fig. 5. Chloride penetration of CS – FS Concrete.

Table 4 Chloride penetration of CS – FS Concrete

Mix	% Replacement		Charge passed (Coulombs)	Permeability
	CS	FS		
CC	-	-	1622	Low
M11	10	15	1566	Low
M12	10	20	1532	Low
M13	10	25	1511	Low
M14	10	30	1477	Low
M21	15	15	1528	Low
M22	15	20	1609	Low
M23	15	25	1588	Low
M24	15	30	1555	Low

4.2 Resistance to Acid

The acid may attack the concrete by dissolving the cement compounds and calcareous aggregate. The weight lost due to the acid attack is tabulated in Table 5. All the mixes have shown higher weight loss percentage when compared to CC. Mixes M21 and M22 have relatively low weight loss percentage compared with normal concrete. The cubes have undergone maximum weight loss for the mix M24.

Table 5. Acid resistance of CS – FS Concrete.

Mix	% Replacement		Dry weight (kg)	Weight after immersed in acid (kg)	Weight loss (%)
	CS	FS			
CC	-	-	2.42	2.21	8.60
M11	10	15	2.39	2.06	13.60
M12	10	20	2.36	2.01	14.83
M13	10	25	2.35	1.98	15.74
M14	10	30	2.34	1.95	16.74
M21	15	15	2.32	2.05	11.64
M22	15	20	2.38	2.09	12.18
M23	15	25	2.35	1.99	15.32
M24	15	30	2.33	1.92	17.60

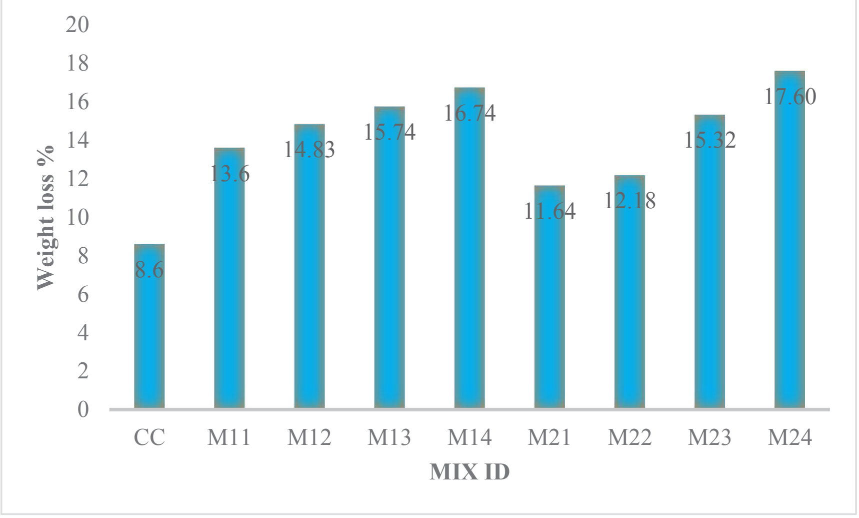

Fig.6. Acid resistance of CS – FS Concrete.

5 Conclusion

The following conclusions were drawn as part of experimental analysis conducted on green sustainable concrete with 10%, 15% coconut shell as coarse aggregate in combination with 15%, 20%, 25%, 30% foundry sand as fine aggregate replacement.

- Concrete with 20% FS and 15% CS performs better than regular concrete in durability tests such the accelerated corrosion test, the quick chloride permeability test, and the acid resistance test.
- Concrete made using foundry sand (FS) and coconut shell helps significantly to the reduction of costs, the preservation of natural resources, and the environmentally responsible disposal of trash.
- Further, the future scope of work can be extended by adopting the waste products such as coconut shell and foundry sand for reinforced concrete structures.

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