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Research Article

Characteristic study on concrete elements using agro-waste as a replacement of fine aggregate

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Abstract

Concrete is the predominant material that is commonly used for all construction engineering practices and the demand for concrete ingredients has increased nowadays. Utilization of agricultural waste helps in meeting the demand and the present study focused on replacement of fine aggregate with agro-waste. Agro-wastes such as Rice Husk Ash, Saw Dust, and Coconut Shell powder were utilized as a replacement for fine aggregate. An experimental investigation was carried out on concrete specimens with varying proportions of 2%, 4%, 6%, and 8% of agro-waste to the weight of fine aggregate. Agro-waste was equally proportioned for the replaced weight of fine aggregate. Agro-waste concrete was compared with conventional concrete (100% - M sand) for the improvement in mechanical properties by examining the results of compressive strength test and split tensile strength test. Also, the performance of concrete specimens was also determined by non-destructive testing. The optimization of the concrete mix for the addition of agro-waste was obtained based on the strength characteristics. The effectiveness of utilizing agricultural waste in concrete with rebars was studied using the chloride ingress test and Open Circuit Potential test. The experimental findings show that 2 to 4% of agro-waste can be utilized efficiently as fine aggregate replacement.

1. Introduction

Concrete is composed of cement which binds fine aggregate together with coarse aggregate. The scarcity of river sand is increasing nowadays and to meet the current demand, many researchers are focusing on fine aggregate replacement with industrial waste, agricultural waste, and domestic waste. Generally, agricultural wastes such as groundnut shells, sugarcane bagasse ash, oyster shell, tobacco waste, Saw Dust (SD), cork, Rice Husk Ash (RHA), and giant reed ash are used as substitute for fine aggregate. These additives preserve the environment as they are non-toxic, biodegradable, and also reduce cost and energy consumption [1, 2]. The consumption of natural resources also gets reduced with the reuse of agricultural waste in concrete [3]. Utilization of agricultural waste helps in meeting the demand for sand and also helps in solving the disposal problem of agricultural waste. Also, sustainable and eco-friendly construction can be made possible by employing agricultural waste as natural aggregate replacement [4].

As a preliminary study, a comprehensive review was carried out with the help of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [5] to identify the agricultural waste used in concrete by researchers in the past. The review was conducted using the SCOPUS database and the keywords “concrete” and “agricultural waste” were added to analyze the articles focusing on utilizing agricultural waste or agro-waste in concrete. The search resulted in 605 documents (as on May 24, 2023). Virtual Operating System (VOS) viewer was used to extract the network of keywords and their co-

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occurrences. Fig. 1 shows the network diagram extracted from VOS viewer. From Fig. 1, it was observed that the most widely used agricultural waste in concrete is rice husk ash, sugar cane bagasse ash, palm oil ash, and coconut shells, (listed in ascending order in terms of keywords occurrences). Also, the keywords including self-compacting concrete, lightweight concrete, and geopolymer concrete were observed and these keywords highlight the effective utilization of agro-waste in enhancing concrete's strength and durability. Many of these studies focused on finding mechanical and durability properties of concrete containing agro-waste.

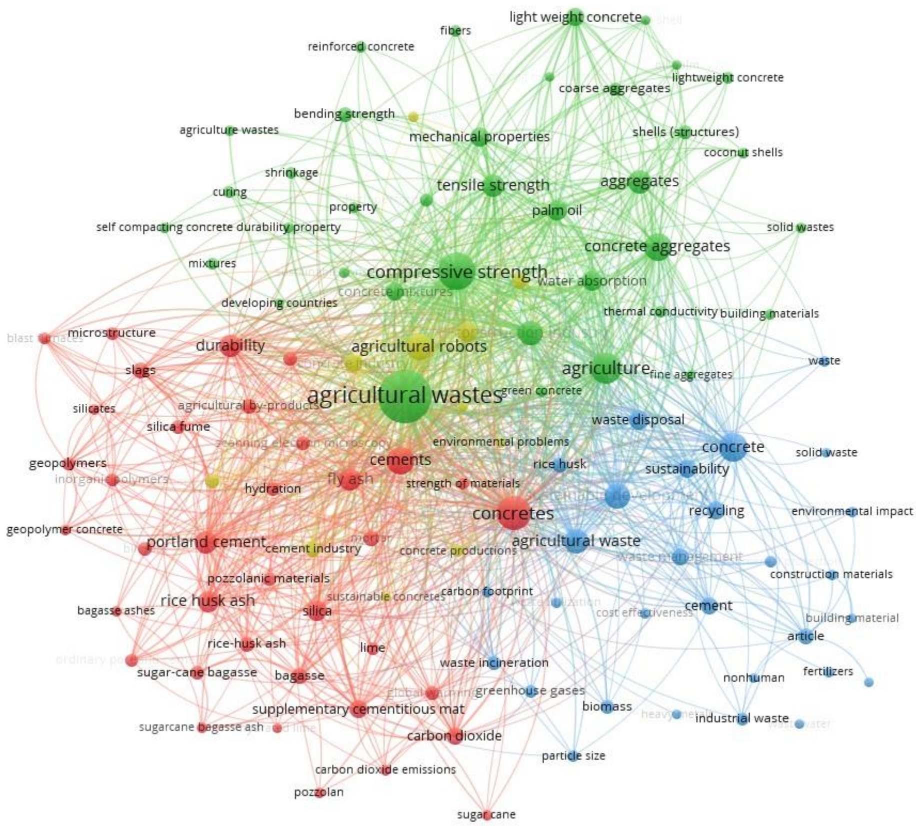


Fig. 1 Network of keywords on utilization of agricultural waste in concrete [Source: VOS viewer]

The current study is mainly concentrated on partial replacement of fine aggregate with eco-friendly additives like Coconut Shell powder (CNS); Saw Dust (SD); Rice Husk Ash (RHA) along with M - Sand to improve the characteristics of concrete. The addition of agro-waste materials (bagasse ash + cork) as fine aggregate replacement in mortar tends to increase the resistance of chloride penetration and improved the cyclic performance of mortar specimens with agro-waste [6]. The utilization of RHA in concrete leads to a reduction in the volume of pores at all ages and decreases the chloride ion penetration [7]. Implementation of ground RHA in concrete with recycled aggregate increased compressive strength, however the modulus of elasticity of concrete declined to that of conventional concrete as RHA concentration increased [8]. The rice husk ash is found effective as a replacement for sand up to 10% [9]. The presence of CSH gel and Ca $(OH)_2$ in concrete with addition to the agro-waste attributed to greater strength and other properties in comparison with conventional concrete for lesser content of agro-waste [10]. Utilization of RHA and Bagasse Ash in Self Compacting Concrete (SCC) resulted in the densification of the microstructure of concrete due to the filler effect and secondary CSH gel formation by pozzolanic reaction [11]. RHA as a partial replacement for fine aggregate is observed to enhance the thermal insulation of the concrete [12]. Being an alternate material for natural sand, the greatest choice for fine aggregate replacement in concrete is sawdust ash because of its unique properties [13]. Fine aggregate replacement by sodium-silicate treated sawdust by 5% is determined as an optimum percentage based on strength characteristics [14]. Coconut shell is a potential agricultural waste resource that can be utilized as a sustainably imperative material in concrete [15]. Use of partial coconut shell aggregate results in the production of concrete with good binder quality [16]. The cost of production of concrete with coconut shell powder gets reduced by 5.87% for 30% replacement of fine aggregate in comparison with conventional concrete [17]. Hence, the efficient usage of coconut shell powder, rice husk ash, and saw dust has been experimentally proven for its effectiveness as replacement for fine aggregate. The present study aims to investigate the combined effect of RHA, SD and CNS as replacement for fine aggregate.

2. Research Significance

The utilization of agricultural waste in concrete helps in producing sustainable concrete. The disposal of huge amounts of waste generates land pollution and effective utilization of agricultural waste results in energy conservation and conservation of natural resources. Hence, amending the agro-waste with the partial replacement for fine aggregate can eradicate the environmental issues. This type of concrete also helps in promoting a sustainable environment.

3. Materials

3.1. Coarse Aggregate

The specific gravity and bulk density were found as per IS: 2386 (Part III)-1963 [25] and the values were 2.89 and 1.56 kg/m^3 respectively. The water content present in the aggregate was found to be 0.35% and the maximum size of aggregate used was 20 mm.

3.2. Cement

Cement being a binding material possesses both adhesive and cohesive characteristics. Grade 53 Ordinary Portland Cement (OPC) was used for casting the specimens. The consistency was found to be 31% and the initial setting time was 39 minutes determined as per IS: 4031 – 5:1988 [27]. The specific gravity was obtained as 3.16 (as per IS:4031 – 11:1988) [28] and the fineness of cement was obtained as 5% (as per IS:4031 – 1:1988) [26].

3.3. Fine Aggregate

M – Sand which was crushed and broken into pieces from hard granite rocks was used as fine aggregate. M – Sand available at nearby places was considered for experimental investigation. The specific gravity of M- sand was 2.63 and its fineness modulus was 3.978. According to IS: 383 - 2016 [21], M- sand is classified as Zone II.

3.4. Rice Husk Ash (RHA)

Rice husk is the primitive element of the agro material, where the external covering, the husk is non-edible and can be used as an intrinsic material for improvement of strength in concrete. Rice husk ash possesses greater pozzolanic reactions which enriches the performance of the concrete [8]. The rice husk had a specific gravity of 2.27. The fineness modulus was determined as 4.31.

3.5. Coconut Shell Powder (CNS)

The coconut shell, which is mostly available in countries like India, Sri Lanka, and Malaysia produces copious quantities of shell which creates problems with disposal; this coconut shell can be dried, powdered, and used as a replacement for fine aggregate in construction industries. The specific gravity of coconut shell powder was determined as 1.2. This possesses a cellulose content of 43.44% which can be one of the reasons for enrichment for strength and possess 45.84% of lignin, and hemicellulose of 0.25% which acts as an impulse for its usability as concrete ingredients [18]. The fineness modulus was determined as 2.46.

3.6. Saw Dust (SD)

Saw dust is a fundamental by-product obtained from the wooden industry and it is easily flammable when it is incautious in disposal. The specific gravity of sawdust was obtained as 2.15. The fineness modulus was obtained as 4.03. The chemical composition of the cement, M-sand, Rice Husk Ash and Saw Dust are given in Table 1.

Table 1. Chemical composition of cement, M-sand, RHA and SD

Composition (%)	Cement	M-sand	Rice Husk Ash	Saw Dust
SiO_2	22.34	68.67	85.02	68.5
Al_2O_3	4.98	15.92	0.53	4.63
Fe_2O_3	4.54	4.98	0.44	3.47
CaO	60.12	2.97	1.51	9.70
MgO	1.22	-	0.42	5.19
SO_3	2.56	-	1.62	0.33
Na_2O	0.36	0.98	1.10	0.07
K_2O	0.51	1.21	2.16	0.23
Loss On Ignition	3.29	3.55	4.93	-

4. Mix Design

The properties of materials were evaluated and based on which the mix proportions were obtained for concrete grade M30 as per Indian Standard IS:10262-2019 [29]. Table 2 shows the adopted mix design for the present study. Batching, mixing, and casting of specimens with agro-waste was done similarly to conventional concrete. Agro-waste was replaced for the weight of fine aggregate by 2%, 4%, 6%, and 8% (with an equal proportion of RHA, CNS, SD for the percentage of replaced fine aggregate). First, the required quantity of cement, M-sand, RHA, CNS, and SD were mixed dry until a uniform mix was obtained and then the content was added to the coarse aggregate in the mixer. Initially, the concrete ingredients were allowed for dry mixing, further required quantity of water was added slowly and mixed to obtain the concrete with the required consistency. Workability of concrete with 100% M-sand was obtained as 100 mm and the slump value decreased by 15% for 8% agro-waste concrete specimens.

5. Methodology and Testing of Concrete Specimens

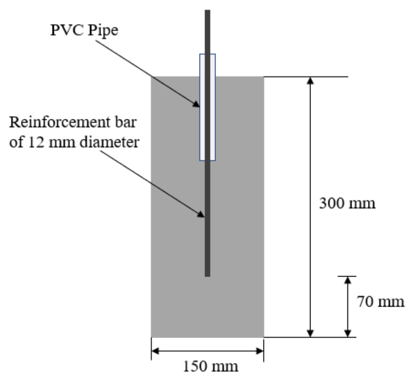
The mechanical properties of M30 concrete grade were determined according to Indian Standard recommendations. The concrete cube of size 150 × 150 × 150 mm, and concrete cylinder with 150 mm diameter and 300 mm height were casted, cured and tested to determine the strength characteristics of concrete. The preparation of the agro-waste concrete was same as conventional concrete, but it includes the addition of agro-waste materials. Rice husk ash, coconut shell powder, and sawdust were equally proportioned, batched, and mixed. The varying percentages to which agro-wastes was replaced for fine aggregate in concrete are 2%, 4%, 6%, and 8% by weight. The concrete specimens were also tested for non-destructive testing to check the concrete quality. The non-destructive testing was performed as per IS: 13311 (Part 1 and 2): 1992 [22, 23]. Based on the experimental test results, the optimum mix was arrived for adding agro-waste to concrete. The optimum mix was used to cast the concrete cylinders with rebars to study the permeability of concrete.

Table 2. Composition of concrete ingredients

Description	Composition
Water cement ratio	0.42
Coarse aggregate	1234 kg/m^3
Fine aggregate	664 kg/m^3
Cement	381 kg/m^3
Mix ratio	1: 1.74: 3.24
Adopted water content	160 litres

5.1. Open Circuit Potential Test

Six numbers of concrete cylinders with rebars were cast with 0% (2), 2% (2), and 4% (2) of agro-waste as replacement for fine aggregate as shown in Fig. 2. Open Circuit Potential test [24] and chloride ingress test were performed on concrete cylinders with rebars to determine the permeability of the hardened concrete. The studies were also conducted to investigate the efficacy of using agro-waste in concrete. Cylinders with rebars were dried in the open air for 24 hours after 28 days of curing. The dried specimens were immersed in 3.5% NaCl for 60 days. The potential readings were measured periodically for 60 days.



a) Details of concrete cylinders with rebar

b) Cast cylinders with rebar

Fig. 2 Casting of cylinder specimens with rebar

5.2. Chloride ingress test

A chloride ingress test was used to find the chloride content that penetrated the concrete cylinders after exposure to 3.5% NaCl for 60 days. The core concrete sample from the cylinders was made into fine powder. Concrete samples passing through a 425-micron sieve were collected and weighed for 20 grams. The 20 grams of powder was mixed with distilled water of 100 ml. The prepared sample was placed in a shaker for 1 hour and was filtered with a filter paper. The filtered sample was utilized for the determination of chloride content. The amount of chloride content was measured and the increase or decrease in chloride content was correlated to the permeability of the concrete.

6. Results and Discussion

6.1. Compressive Strength Test

A compressive strength test was performed for the conventional concrete with 100% M-sand and agro-waste concrete after the required days of 3-, 7-, 14- and 28-days water curing. Table 3 shows the compressive strength results for both concrete with 100% M-Sand and agro-waste concrete with 2 - 8% of agro-waste as fine aggregate replacement. From Table 3, it was observed that agro-waste concrete has achieved the required design target strength except for agro-waste concrete specimens with 8% of agro-waste.

Table 3. Compressive strength of concrete

% of agro-waste	Compressive strength – 3 days (N/mm^2)	Compressive strength - 7 days (N/mm^2)	Compressive strength – 14 days (N/mm^2)	Compressive strength - 28 days (N/mm^2)
0%	21.38	27.59	38.46	41.2
2%	19.26	23.3	37.06	37.7
4%	21.83	26.96	38.30	39.8
6%	17.23	25.42	29.83	34.26
8%	9.8	22.12	23.03	27.35

From Fig. 3, it was inferred that the pattern of the compressive strength gain curve remains the same for concrete with 100% M-sand and agro-waste concrete with 2% and 4% of agro-waste. Also, it was observed that the addition of agro-waste does not affect the early-age strength development of concrete.

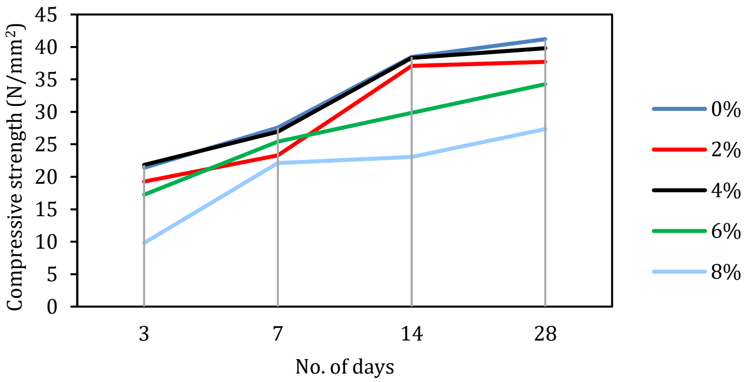


Fig. 3 Compressive strength of concrete specimens for varying percentage of agro-waste

Fig. 4 represents the compressive strength variation for agro-waste concrete to the varying percentages of agro-waste materials. From the 28-day test results, it is inferred that agro-waste concrete with 4% replacement has good performance compared with other agro-waste concrete specimens. Also, it is inferred that the addition of agro-waste for replacement of fine aggregate beyond 6% results in a decrease in compressive strength by approximately 27%. All the concrete specimens with agro-waste concrete were found to have compressive strength value lesser than conventional concrete but the required target strength has been achieved with the replacement by 4% of agro-waste. The decrease in compressive strength with an increase in agro-waste content can be attributed due to the water absorption by RHA [8, 19], SD, and CNS [17]. The decrease in compressive strength with the increase in agro-waste beyond 10% was also observed by previous researchers [8, 17, 19, 20].

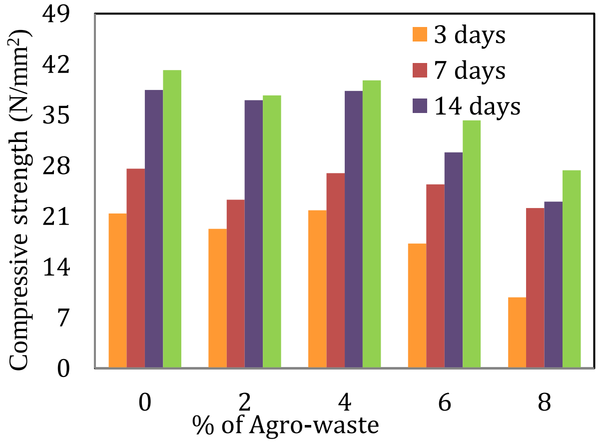


Fig. 4 Compressive strength of concrete with varying % of Agro-waste

6.2. Split Tensile Strength

The split tensile strength was performed for varying percentages of agro-waste in which the 4% confirms again to be an optimized percentage as it possesses the value of 2.94 N/mm^2. Fig. 5 shows a graphical depiction of the 28-day split tensile strength results. The results from split tensile strength test follows a similar trend to compressive strength test results and from the test results it was observed that 4% of agro-waste can be replaced for fine aggregate using M- Sand.

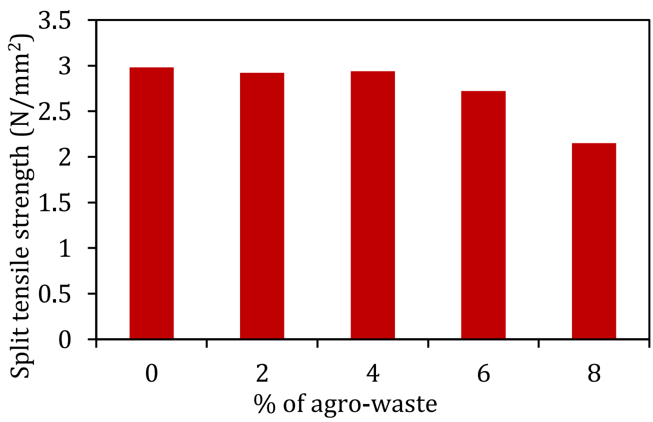


Fig. 5 Split tensile strength of concrete with varying % of agro-waste

6.3. Rebound Hammer Test

The rebound hammer results for agro-waste concrete specimens are up to scratch compared to standard concrete. The rebound value obtained for 4% of agro-waste concrete is 31.0 whereas for conventional concrete it gives 31.4. Table 4 shows the rebound value and the corresponding compressive strength for specimen with varying percentages of agro-waste. Test results show that concrete specimen with 4% of agro-waste shows fairly good surface characteristics with compressive strength of 28 N/mm^2 when compared with other agro-waste concrete specimens.

Table 4. Rebound hammer values with varying % of agro-waste

Specimen with agro-waste	Rebound number value	Compressive strength (N/mm^2)	Concrete quality as per IS: 13311 [23]
0%	31.4	29	Fair
2%	29.9	27.5	Fair
4%	31.0	28	Fair
6%	28.8	27	Fair
8%	27.6	26	Fair

6.4. Ultrasonic Pulse Velocity Test

Table 5 shows the quality of concrete determined based on pulse velocity. The test findings show that the quality of concrete cubes containing 0%, 2% and 4% agro-waste is excellent. The homogeneity of concrete was maintained with the replacement of fine aggregate by agro-waste. An increase in agro-waste percentage beyond 4% results in the reduction of uniformity of concrete mixes and this can be due to the fact that the addition of agro-waste beyond 4% results in non-uniform packing and unequal dispersion of agro-waste into concrete.

Table 5. Ultrasonic pulse velocity test results with varying % of agro-waste

Specimen with agro-waste	Velocity (km/s)	Concrete quality as per IS: 13311 [22]
0%	4.61	Excellent
2%	4.58	Excellent
4%	4.60	Excellent
6%	4.33	Good
8%	3.98	Good

6.5. Open Circuit Potential Test

The results obtained on 6 concrete cylinders for 60 days are given in Fig. 5. It was observed from the test results that the corrosion rate for agro-waste concrete with 2% and 4% of agro-waste was lesser in comparison with concrete with 100% M-sand (0% of agro-waste). Also, the trend in the increase in potential values for concrete specimens was noticed with the increase in days. The corrosion condition was defined based on potential values in ASTM C876 [24] and the risk of corrosion is highlighted in Fig. 6. The corrosion rate was initially low from 1 to 11 days for all specimens; intermediate corrosion risk was observed from 12 to 55 days, and agro-waste concrete specimens were subjected to intermediate corrosion risk at the end of 60 days. A high risk of corrosion was observed in conventional concrete specimens from 55 to 60 days. The improvement in the performance of agro-waste concrete can be due to the micro-filling effect of RHA within the cement particles [19]. The hydration products get distributed in a homogenous manner and make the concrete matrix denser with the addition of RHA [7]. Thus, the addition of agro-waste resulted in improved performance in terms of micro-filling ability.

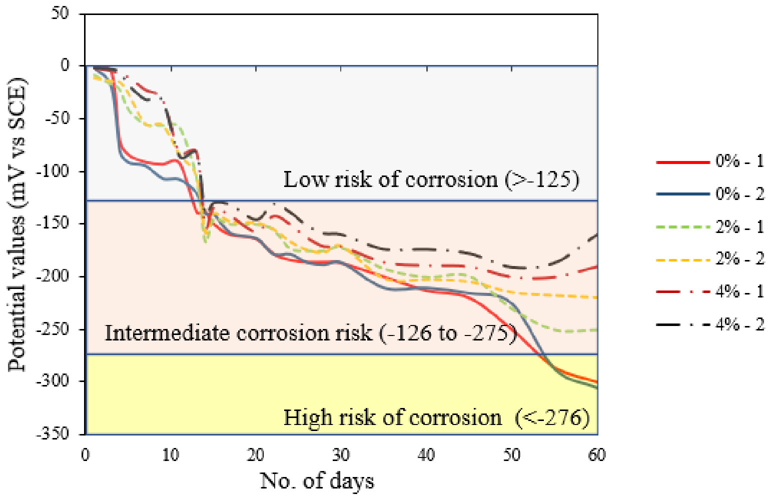


Fig. 6 Potential values for concrete specimens with 0%, 2% and 4% of agro-waste

6.6. Chloride Ingress Test

The quantity of chloride penetrated through the concrete specimens was determined using the chloride ingress test and the chloride content was determined by titration against silver nitrate solution with potassium chromate 5% as the indicator. Table 6 gives the quantity of chloride content penetrated through the concrete specimens and it is clear that agro-waste concrete specimens had a lesser amount of chloride penetrated. Hence, the permeability of concrete had been improved with the utilization of agro-waste as a replacement for fine aggregate.

Table 6. Chloride content for concrete specimens with 0%, 2% and 4% of agro-waste

% of agro-waste	Mean value of silver nitrate solution (ml)	Obtained chloride content (mg/L)	% Decrease in chloride content with respect to conventional specimen
0	10.50	149.1	-
2	9.55	135.6	9.02
4	9.30	132.0	11.47

7. Conclusion

Experimental investigation was performed to ascertain the robust strength of utilizing agro-waste in concrete for 0%, 2%, 4%, 6% and 8% as fine aggregate replacement and the strength characteristics were determined to find the optimized percentage. The following concluding remarks are arrived based on the results from experimental investigation:

- It is recommended to utilize agro-waste with an equal proportion of rice husk ash, sawdust, and coconut shell powder as a replacement for fine aggregate from 2% to 4% by weight.
- It is profound that 4% of agro-waste was obtained to be an optimized percentage for agro-waste concrete as the laboratory results are more convincing for 4% compared with conventional concrete (100% M-sand). The compressive strength and split tensile strength obtained for 4% are also more competent and comparable to conventional concrete.

- Based on the test results from non-destructive testing, it is observed that the surface characteristics and homogeneity of concrete were not affected with the addition of agro-waste up to 4% as a replacement for fine aggregate.
- The addition of agro-waste beyond 4% was found to be ineffective, as evidenced by the lower performance of 6% and 8% agro-waste concrete specimens.
- The experimental results from the OCP test shows that the potential values are lesser for agro-waste concrete specimens in comparison with concrete specimens with 100% M-sand. Also, the chloride content penetrated into the concrete core is lesser for agro-waste concrete specimens. Hence, it is inferred that agro-waste had the micro-filling ability that resulted in the reduction of permeability of concrete specimens. Thus, the replacement of fine aggregate by agro-waste between 2% to 4% is effective in concrete elements with rebars.
- The utilization of agro-waste in concrete will reduce conventional material usage and also it is an environmentally benign. Hence effective utilization of agro-waste will be substantial to the environment.

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