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Strength and durability properties of concrete made with recycled coarse aggregate and seashore sand

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Abstract

The process of depletion of sources of natural aggregates poses challenges to produce technically and environmentally suitable concrete. Aggregate compositions found in construction and demolition (C&D) waste offer potential alternatives to natural coarse aggregates. Additionally, the utilization of abundantly available natural material like seashore sand, as a replacement for river sand, can present a viable solution to this problem. This research paper investigates the performance of concrete that incorporates 40% recycled coarse aggregates, along with varying percentages of seashore sand as replacements for river sand (0%, 10%, 20%, 30%, 40%, 50%, and 100%). The evaluation focuses on strength properties, including compressive strength tests on cylinders and impact resistance tests, as well as durability properties such as water penetration tests under pressure and sulphate attack tests. The experimental results indicate that concrete incorporating both recycled coarse aggregates and seashore sand replacements yields favorable outcomes in terms of strength and durability when compared to the controlled concrete, particularly at suitable replacement proportions.

Keywords:
Compressive strength on cylinder;
Impact resistance;
Recycled coarse aggregates;
Seashore sand;
Sulphate attack test;
Water penetration under pressure;

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INTRODUCTION

The booming construction industry is rapidly increasing carbon emissions and energy consumption. Excessive concrete usage is a significant environmental concern, leading to high demand for natural aggregates and river sand, while also challenging the sustainability of the construction sector in various regions. Consequently, it is imperative to seek alternative solutions for concrete production, reducing reliance on natural resources.

Concrete Engineering's rapid progress has raised significant environmental and social concerns such as pollution and excessive resource consumption. Construction waste production is rapidly growing, and there is a consistent high demand for river sand and natural coarse aggregates. [1]. The literature review highlights higher water absorption in recycled aggregate compared to natural coarse aggregate concrete, primarily due to lose adhered mortar. Various treatment methods have been employed to enhance its quality for concrete use [2].

Recycled Aggregate Concrete (RAC) faces limitations in structural applications due to its subpar durability performance. To address this, a study examined five distinct treatment methods for recycled aggregate (RA): The methods studied were immersion in acetic acid, immersion in acetic acid with rubbing, accelerated carbonation, immersion in acetic acid with accelerated carbonation, and immersion in line with accelerated carbonation. The goal was to assess how these techniques influenced the durability of recycled aggregate concrete [3].

RAC offers sustainability through the use of construction debris and demolition waste as a replacement for natural coarse aggregates. However, aged mortar in Recycled Aggregates (RCA) is a common issue, which diminishes concrete strength and leads to problems such as higher water absorption, reduced workability, and increased drying shrinkage [4]. The conventional approach entails heating the RCAs or using acids or mechanical treatment to weaken the cement mortar adhered to the RCA surface and enhance the mechanical properties of concrete manufactured with treated RCAs as aggregates [5][6]. However, using strong acids like hydrochloric and sulfuric acid in the conventional approach poses safety risks for workers and introduces harmful ions such as Cl^- and SO_4^{2-} into the recycled concrete aggregates (RCAs), potentially causing strength and durability issues. This study introduces a novel chemical process that utilizes a low concentration of acetic acid (1-5%). The recycled concrete aggregates (RCAs) are submerged in a diluted acetic acid solution, instigating reactions with different elements in the cement mortar. This process efficiently detaches the adhering mortar and enhances the quality of the aggregates. Furthermore, this treatment process ensures worker safety, reduces costs, maintains cleanliness, and prevents the introduction of detrimental ions into the RCAs. [7][8]. In several nations, researchers are investigating substitute materials to replace river sand in concrete manufacturing. These alternatives encompass sea sand, ROBO sand, glass powder, stone dust, and other options. Sea sand, for instance, is easily accessible but generally contains high chloride levels [9]. It is crucial to remove chloride content from sea sand, as it significantly influences both the workability and the durability of the structure. [10].

The study presents a method to remove salt and micro-organic matter from sea sand, making it suitable for construction. Boiling and multiple water washes are used, along with a chemical solution to enhance the sand properties. This treatment aligns sea sand with river sand, allowing its partial replacement in concrete production. The research shows improved performance in compressive and tensile strength compared to the control concrete [11].

Mahalakshmi et al. and Samraj P and Nagarajan adopted the salinity removal technique such as simulated rain test, mechanical washing, influence of temperature on solubility, leaching techniques for their research work [12][13]. In their research work, Kartheek Thunga and T. Venkat Das utilized salt removal techniques, including hypo treatment and washing processes, soaking processes, and boiling processes [11].

The study proposes using offshore sand, located 2 to 7 km from the Western coast, as a viable alternative to river sand, supported by factors like availability, ease of extraction, environmental benefits, and cost-effectiveness. However, some offshore sand deposits may require washing to remove organic matter and contaminants not effectively removed by sieving. [14]. Abundant seashore sand, piled as high as 30 meters in the Muthurajawela area along the Sri Lankan coast, is readily available to the public for use in construction.

Experimental studies demonstrate that even small amounts of washed seashore sand can offer satisfactory strength similar to river sand in conventional concrete. Over one to two years of natural exposure to monsoon conditions, the chloride content diminishes, rendering seashore sand suitable for concrete production [15].

This project involves the use of hypo sludge (waste sludge from paper industry) in M30 grade concrete, replacing cement at varying percentages (10%, 15%, 20%, 25%, and 30% by weight). The study shows that a 15% replacement of hypo sludge leads to the most significant reduction in compressive strength, with a decrease of 27.9%. The minimum reduction in compressive strength is observed with a 10% replacement compared to conventional concrete [16]. The results of standardized cylinder compressive strength tests positively impact the use of recycled coarse aggregates from crushed concrete cylinders in the construction industry [17]. Based on the cylinder compressive strength outcomes, substituting untreated recycled coarse aggregates from demolition waste at a rate of 10% instead of natural aggregates is an optimal solution [18].

Impact energy in recycled aggregate concrete is assessed through an empirical relationship. It reveals that replacing 50% of treated recycled coarse aggregate with natural aggregates increases impact strength. However, with higher replacement levels, impact strength decreases [8]. Generally, the use of recycled aggregates tends to increase water penetration levels. However, the study reveals that water penetration does not significantly increase, making recycled aggregate a viable option.

The study suggests that recycled coarse aggregate can effectively replace natural aggregate up to 40-45% without a significant decline in strength and durability, as indicated by compressive strength, rapid chloride penetration, and water permeability tests [19].

The results found for water penetration depth under pressure were almost the same for marine sand replacement for river sand with mix ID CB35%, CB50% and CC50% and less comparable to reference concrete [20]. The replacement of 24% pretreated recycled coarse aggregate with a 0.5% polyvinyl alcohol solution, combined with sealed curing conditions, reduces concrete absorption by 1.01%, improving sulfate attack resistance [21].

Muhammad Zakaria Umar et al., aimed to evaluate concrete bricks with sagu fiber, testing various compositions with 0%, 50%, 60%, and 70% sagu fiber. Lab results identified the ideal mix for high quality as 70% sagu fiber and 30% sand [22].

The optimal combination of sea sand and desert sand to substitute for fine aggregates (river sand) in cement mortar blocks was established through compressive strength tests. The ideal proportion was found to be 30% sea sand to river sand and 30% desert sand to river sand [23].

The test outcomes consistently showed that concrete using sea sand had higher compressive strength when compared to concrete using river sand. [24]. Furthermore, there was a significant enhancement of approximately 30% in compressive strength and 35% in flexural strength observed in air-cured polymer concrete with 20% sea-sand substitution at 180 days, in comparison to conventional concrete [25].

Most of the literature review focuses on concrete made by substituting either coarse aggregate with RCA or fine aggregate with seashore sand. In our project, we used concrete where both the coarse aggregate was replaced with RCA and the fine aggregate with seashore sand simultaneously.

MATERIAL AND METHOD

The material and method section of a research paper provides a detailed description of the materials used and the procedures followed during the study.

Materials

According to IS: 12269-1987, we employ Ordinary Portland Cement with a 53-grade designation, indicating that its compressive strength reaches 53N/mm2 after 28 days of curing cement mortar cubes. The cement's chemical composition is outlined in Table 1. The river sand, a natural material employed in construction, exhibits different proportions in grade classification. Natural River Sand conforming to IS383 (1987) and IS 10262-2009 was utilized.

The fine aggregate consists of both River sand and Sea sand. In this study, we conducted sieve analysis on both the river sand and sea sand. We weighed and recorded the amounts of particles retained in each sieve, arranged in descending order in Table 2. The river sand comes under zone II. The texture of seashore sand can vary significantly from that of river sand deposits. The seashore sand gathered from the eastern coastal region of Parangipettai, Tamil Nadu, India, can be used as a replacement for river sand and falls within zone IV classification. Crushed granite coarse aggregate with nominal sizes of 20 mm and 10 mm conforming to IS: 383 (1987) was utilized. Recycled coarse aggregate was sourced from the nearby institutions, Cheyyar, Tamil Nadu. The RCA was crushed into 20 mm and 10 mm sizes using a hammer.

The specific admixture employed in this project is Conplast SP430, which accelerates the strength gain in concrete during early stages and enhances strength at all ages by reducing water demand. Conplast SP430 is a concrete additive that enhances water dispersion and improves effectiveness. Despite a 0.45 water-cement ratio in M30 grade concrete, recycled coarse aggregate (RCA) can increase water absorption.

Conplast SP430 is employed to maintain the desired workability (typically 50mm to 75mm, assessed via a slump test). This additive regulates concrete consistency and flow, ensuring ease of use while meeting performance standards. The characteristics of all materials are presented in Tables 3, 4 ,5 & 6.

Methods

Methods employed to enhance the attributes of Recycled Coarse Aggregate (RCA) and Seashore Sand.

Table 1. Chemical composition of cement in %

SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	SiO3	Loss on ignition
18.91	4.51	4.94	66.67	0.87	0.43	0.12	2.5	1.05

Table 2. Sieve analysis of fine aggregate proportions

Sieve analysis	Percentage of seashore sand replacement in river sand						
	0	10	20	30	40	50	100
	Percentage passing						
10.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0
4.75	93.5	98.5	99.5	98.5	96.5	99.0	100.0
2.36	88.0	93.0	96.0	95.5	94.0	96.0	99.0
1.18	55.5	53.5	61.5	76.0	75.5	76.5	98.0
0.60	39.0	35.0	28.0	57.5	60.0	62.0	82.5
0.30	15.5	8.5	12.5	19.5	19.0	17.0	25.5
0.15	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Zone	**II**	**II**	**II**	**II**	**III**	**III**	**IV**
Fineness modulus	3.09	3.11	3.02	2.52	2.55	2.50	1.95

Table 3. Physical Properties of Cement

Properties	Cement
Specific gravity	3.18
Normal Consistency in %	33
Initial Setting time in minutes	50
Final Setting time in minutes	260
Fineness in %	4.5

Table 4. Physical Properties of Fine Aggregates

Properties	River sand	Seashore Sand
Bulk density, kg/m^3	1565	1580
Specific gravity	2.72	2.64
Fineness modulus	3.09	1.95

Table 5. Physical Properties of Coarse Aggregates

Properties	Natural coarse Aggregate	Recycled Coarse Aggregate
Bulk density, kg/m^3	1526	1409
Specific gravity	2.83	2.78
Fineness modulus	7.2	7.41
Impact value %	9.24	15.88
Crushing value %	14.83	24.66

Table 6. Chemical properties of fine aggregates

Properties	River Sand	Untreated Seashore Sand	Treated Seashore Sand
PH Value	7.89	8.32	8.15
Chloride, mg/l	98	467	208

Treatment process of Recycled Coarse Aggregate

The concrete debris was manually broken using a hammer to achieve the desired size of RCA. Subsequently, the RCA samples were air-dried before immersing them in a 1% acetic acid solution at room temperature for 24 hours The container was intermittently stirred to facilitate optimal interaction between the acid and the loosely adhering particles on the initial aggregate. Following a one-day immersion, the aggregates were removed from the solution and air-dried. The recycled coarse aggregate (RCA) used in this study had a nominal size of less than 20 mm. [7,8].

Treatment process of seashore sand

The sea sand obtained for this research was stored in an uncovered location and subjected to environmental elements such as rainfall and atmospheric conditions for a duration of one year to eliminate salinity.

This natural treatment approach necessitates minimal intervention and is economically viable [14][15].

Concrete mix design

The concrete mix employed was designed as per IS 10262-2009, with a grade of M30. In this designation, 'M' denotes Mix, and the number indicates the expected characteristic compressive strength of the concrete, which is 30MPa or 30N/mm^2, determined through testing 150 mm cube specimens at the age of 28 days. The details of the concrete mix design are presented in Table 7 and 8.

EXPERIMENTAL PROCEDURE

Compressive strength

We conducted compressive strength tests on both 150mm x 150mm x 150mm cube specimens and cylindrical specimens measuring 150mm x 300mm, following the procedures outlined in IS 516-1959, as depicted in Figure 1 and 2. Compressive strength tests were conducted on cube specimens for both the control concrete and concrete samples with varying replacement percentages (10%, 20%, 30%, 40%, 50%, 75%, and 100%) of natural coarse aggregate with treated Recycled Coarse Aggregate (RCA) to determine the optimal RCA replacement.

Table 7. Mix proportion of concrete mix

Weight	Cement	Fine aggregate	Coarse aggregate	Water	W/C ratio	Super plasticizer
Materials in kg/m^3	422	680	1205	190	---	1.43
Mix ratio	1	1.61	2.86	---	0.45	0.34%

Table 8. Details of Mix proportion

S.No.	% replacement of RCA	% replacement of seashore sand	Cement	River sand	Seashore sand	Natural coarse aggregate	Recycled coarse aggregate	Remarks
1.	0	0	422	680	0	1205	0	CONTROL
2.	40	0	422	680	0	723	482	USS0
3,		10	422	612	68	723	482	USS10
4.		20	422	544	136	723	482	USS20
5.		30	422	476	204	723	482	USS30
6.		40	422	408	272	723	482	USS40
7.		50	422	340	340	723	482	USS50
8.		100	422	0	680	723	482	USS100
9.	40	0	422	680	0	723	482	TSS0
10.		10	422	612	68	723	482	TSS10
11.		20	422	544	136	723	482	TSS20
12.		30	422	476	204	723	482	TSS30
13.		40	422	408	272	723	482	TSS40
14.		50	422	340	340	723	482	TSS50
15.		100	422	0	680	723	482	TSS100

Figure 1. Cube compressive strength test

Figure 2. Cylinder Compressive strength test

Once the optimal RCA replacement was established, cylindrical concrete samples were prepared, replacing river sand with seashore sand in varying percentages (10%, 20%, 30%, 40%, 50%, and 100%) to identify the optimal seashore sand replacement. Each test included three samples, and the average values were recorded as the specimen strength.

The load causing failure was noted, and the compressive strength (fck) was determined using the following equation:

$$\text{Compressive Strength}, f_{ck} = \frac{Load\ at\ failure\ in\ N}{Cross\ sectional\ area\ of\ specimen\ in\ mm^2} \quad (1)$$

Impact Strength

Cylindrical specimens measuring 152mm in diameter and 63.5mm in height were used for the impact energy test in compliance with the regulations set by ACI Committee 544. The concrete's impact resistance at 28 days was assessed using the drop weight method, as illustrated in Figure 3.

A 4.54kg hammer is released from a height of 457mm above a small ball positioned on the top of the specimen. This procedure is iterated until the sample exhibits its initial visible crack and ultimately reaches failure.

We record the count of blows at the first visible crack (N1) and at the point of failure (N2). The calculation of the impact energy delivered to the specimen is as follows.

$$\mathrm{EI} = Nmgh \quad (2)$$

where,

EI - impact energy (Nm),
N - the number of blows, (N=N2–N1)
M - the mass of the drop hammer (kg),
g - gravity acceleration (m/s2), and
h - the height of drop hammer (m).

Figure 3. Impact strength test

Water Penetration Test

The examination is carried out in accordance with the figure provided, adhering to the protocols outlined in IS 516 (part2/sec1):2018 and the German standard DIN 1048. The test utilizes concrete specimens with dimensions of 150x150x150 mm, aged 28 days. The air-dried concrete samples are positioned on the table with suitable rubber gaskets beneath them. A pressure of 500 KPa (5 bars) is applied to the specimens for a duration of 72 hours, as depicted in Figure 4.

Following the designated time interval, all specimens undergo splitting using a compression testing machine, aided by the equipment's provided splitting device. The depth of water penetration is visually assessed using a vernier caliper, as illustrated in Figure 5, and the corresponding values are recorded.

Figure 4. Water penetration test

Figure 5. Measuring depth of water penetration

Sulphate Attack Test

The test for sulphate attack was performed on a concrete cube with dimensions of 100mm x 100mm x 100mm, as depicted in the Figure 6. The concrete specimen was immersed in clean, fresh water and cured for 28 days before testing. At the end of the 28-day curing period, the specimens were weighed (W1).

Following that, the specimen was submerged in a 5% sodium sulfate solution by weight of the water for a 30-day sulfate attack test. The pH of the solution was carefully maintained over the 30-day period through periodic solution changes.

After 30 days, the specimen was removed from the sulphate solution and weighed (W2) before being tested using a compression testing machine.

Figure 6. Samples curing under sulphate solution

RESULTS AND DISCUSSION

Compressive Strength on Cube

The outcomes of the 28-day compressive strength test on cubes were visually depicted in Figure 7. The graph vividly demonstrates that the compressive strength of concrete with a 40% RCA replacement surpasses that of conventional concrete.The reason is the quality of RCA was improved by acetic acid treatment and comparable to natural coarse aggregate and also tiny presence of adhered mortar on RCA reacts with fresh mortar increase the compressive strength upto 40% replacement of RCA..However, beyond a 40% RCA replacement, As the amount of adhered mortar increases, the bond between the cement paste and recycled aggregates may not be as robust as with natural aggregates. This can result in decreased interlocking and a reduction in compressive strength.

In order to ascertain the ideal seashore sand replacement level, a constant 40% RCA replacement was maintained, while seashore sand was used as a replacement for river sand in different ratios, ranging from 0% to 100%. The optimal replacement level of seashore sand was determined by conducting the following strength-test such as compressive strength using cylinder specimens and impact strength tests on concrete, durability test such as water penetration tests under pressure, and sulphate attack tests.

Compressive Strength on Cylinder

Remarkably, as depicted in the graphical representation Figure 8 and 9, the concrete mixture containing 40% RCA (Recycled Coarse Aggregate) and 30% seashore sand demonstrated a remarkable 9.14% increase in compressive strength when compared to the control concrete.

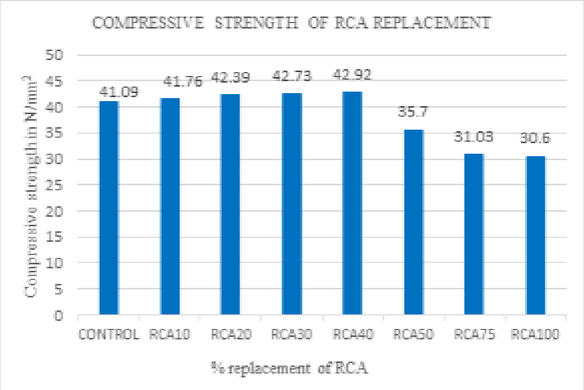

Figure 7. Compressive strength of RCA replacement

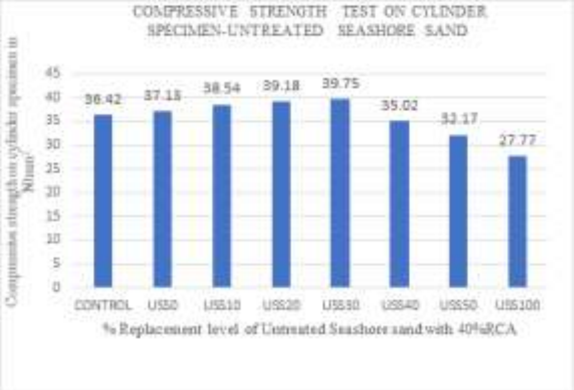

Figure 8. Compressive strength test on cylinder specimen-untreated seashore sand

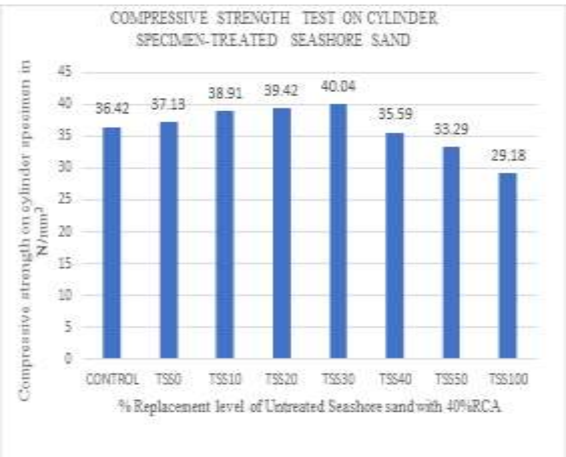

Figure 9. Compressive strength test on cylinder specimen-treated seashore sand

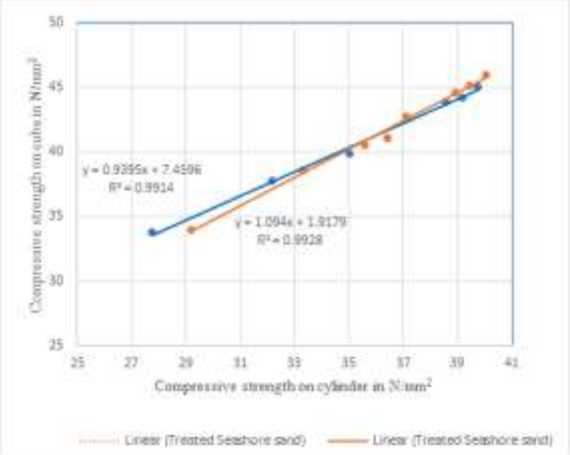

Figure 10. Correlation between compressive strength of cube and cylindrical specimen

This enhancement can be ascribed to the inclusion of fine seashore sand particles, that occupy the small pores in the adhered mortar on the RCA surface, up to a 30% replacement level. However, the results reveal a gradual decrease in concrete compressive strength as seashore sand replacement exceeds 30%.

The reduction in compressive strength can be ascribed to the finer characteristics of seashore sand particles, which augment the specific surface area and fall under zone IV in particle size classification. Based on the findings, it can be inferred that the inclusion of treated seashore sand in concrete yields superior results compared to untreated seashore sand, primarily due to the partial removal of chloride content.

The graphical representation further highlights a significant correlation between the compressive strength of cube specimens and that of cylindrical specimens across all concrete mixtures. Both the untreated seashore sand concrete and the treated seashore sand concrete with 40% RCA replacement exhibited a strong correlation, as depicted in Figure 10 evidenced by the substantial R-squared values of 0.99.

Impact Strength Test

The results of the impact strength test are visually displayed in Figure 11 and 12. Based on the findings, the concrete mixture with 40% RCA (Recycled Coarse Aggregate) and no seashore sand showed an impact strength 8.16% lower than that of the control concrete.

However, with the escalation in seashore sand replacement to 10%, 20%, and 30%, the impact strength of the concrete mixture gradually increased. At 40% and 50% replacement of seashore sand, the impact strength started to decrease.

Nevertheless, even at these replacement levels, the impact strength of the concrete mixture remained higher than that of the control concrete. Several factors contribute to these findings. Firstly, when analyzing the particle size distribution curve, it was found that replacing river sand with seashore sand up to 30% classified the mix within zone II. This classification enhances the resistance to impact loads, particularly at the 30% seashore sand replacement level.

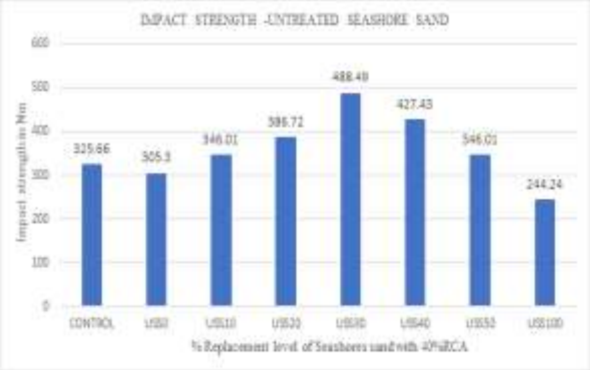

Figure 11. Impact strength test- untreated seashore sand

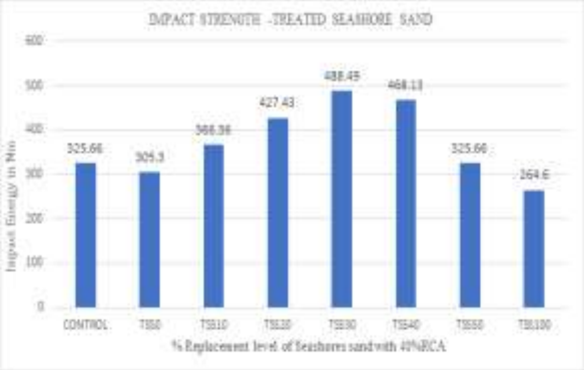

Figure 12. Impact strength test -treated seashore sand

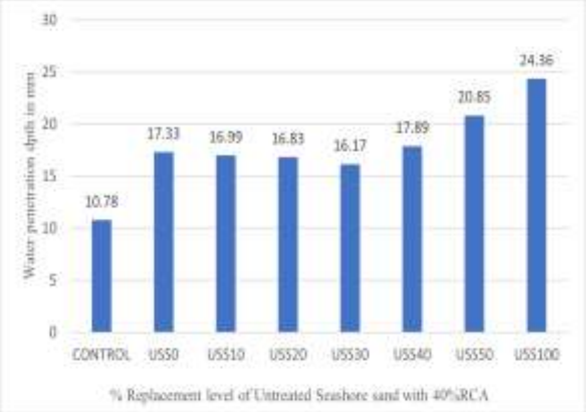

Figure 13. Water penetration test- untreated seashore sand

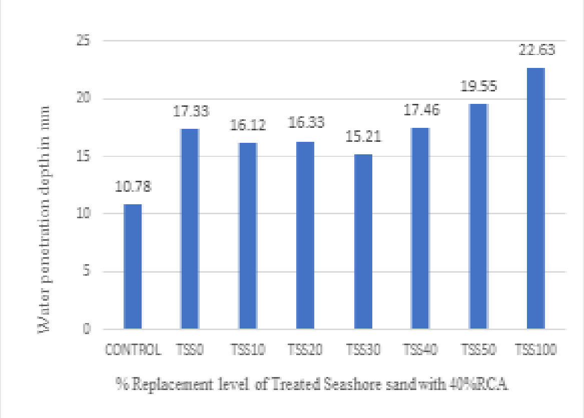

Figure 14. Water penetration test- treated seashore sand

Secondly, in the concrete mixture with 0% seashore sand replacement and 40% RCA, the presence of porous adhered mortar on the surface of RCA led to a reduction in impact strength. However, when seashore sand was added, it filled the minute pores in the adhered mortar of the treated coarse RCA, leading to an increase in the impact energy absorbed by the concrete mixture, particularly up to a 30% replacement of seashore sand.

Above this replacement threshold, there was a decline in the absorbed impact energy, attributed to the finer nature of seashore sand particles. The outcomes suggested that treated seashore sand yielded superior impact strength values compared to untreated seashore sand.

This can be ascribed to the partial removal of chloride content in the treated seashore sand, which positively influenced the impact strength of the concrete mixture.

Water Penetration Test under Pressure

Water permeability in concrete predominantly arises from the interconnected pores within the material. The results from the experimental program indicate that all samples fall within the low permeability range, as demonstrated in Figure 13 and 14. Aggregates possess pores, typically discontinuous, and are surrounded by the highly porous cement paste. This porous nature of the cement paste can significantly influence the permeability of concrete. It was observed that highly porous recycled aggregates might serve as pathways, leading to increased permeability in concrete samples, particularly in the concrete mixture of 40% RCA and 0% seashore sand.

The experimental results reveal that the control concrete exhibited the lowest water permeability, with an average penetration depth of 10.78 mm. In contrast, concrete with 40% RCA and 30% seashore sand showed relatively low average penetration depths of 16.17 mm and 15.21 mm, respectively, when compared to the other concrete mixtures, except for the control concrete.

It was noted that all these values fell within the low water permeability range, and the maximum allowable water penetration depth, as per DIN standards, is less than 25 mm. The concrete with 40% treated recycled aggregates and 0% seashore sand provided permeability higher than control concrete and further permeability is reduced by fine particles of seashore sand replacement up to 30%which could fill the pores of adhered mortar in RCA.

Beyond 30% seashore sand replacement increases the permeability due to presence of more fineness and increased specific surface of seashore sand.

Sulphate Attack Test

The sulphate resistance test values are tabulated in Table 9 and shown graphically in Figure 15. The initial compressive strength of the concrete, prior to exposure to a sulphate attack, ranged from 34.10 N/mm^2 to 45.47 N/mm^2, whereas the control concrete exhibited a compressive strength of 39.42 N/mm^2.

This indicates that the concrete with 40% RCA and 30% seashore sand exhibited higher compressive strength than the control concrete at 28 days, but a similar decline in strength was noted after 30 days of sulphate exposure.

Concrete with 40% treated recycled coarse aggregate and 0% seashore sand replacement shows decreased sulphate attack resistance due to adhering mortar on the recycled aggregate. However, substituting seashore sand (10-30%) fills smaller pores in RCA and also the interaction of cement's C_3A component with chlorides during hydration forms an insoluble compound called Friedel's salt($3CaO\_Al_2O_3\_CaCl_2\_10H_2O$), which fills pores in the cement paste creates a dense microstructure [3], resulting in higher resistance to sulphate attack up to 30% seashore sand replacement.

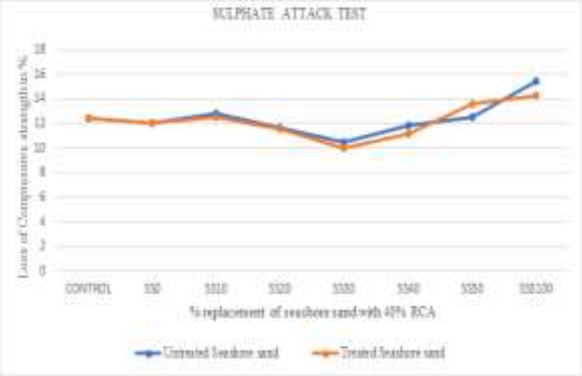

Figure 15. Sulphate attack test

Table 9. Variation of compressive strength due to sulphate attack

S.No	% replacement of Seashore sand with 40% RCA	Average Compressive strength of untreated seashore sand at 28 days in N/mm^2	Average Compressive strength of treated seashore sand at 28 days in N/mm^2	Untreated Seashore sand		Treated Seashore sand	
				Average Compressive strength at 30 days of acid immersion in N/mm^2	Percentage loss of compressive strength at 30 days	Average Compressive strength at 30 days of acid immersion in N/mm^2	Percentage of loss compressive strength at 30 days
1.	control	39.42	39.42	34.52	12.43	34.52	12.43
2.	0	41.27	41.27	36.30	12.04	36.30	12.04
3.	10	42.50	42.88	37.03	12.86	37.50	12.55
4.	20	43.02	43.45	38.02	11.62	38.43	11.55
5.	30	45.47	45.63	40.72	10.45	41.05	10.04
6.	40	37.77	38.10	33.28	11.87	33.85	11.15
7.	50	36.47	37.03	31.88	12.57	31.98	13.64
8.	100	34.10	34.50	28.85	15.40	29.58	14.26

Beyond 30% seashore sand replacement, the finer particles of seashore sand mix with river sand, increasing pores and reducing sulphate attack resistance. This suggests that the concrete incorporating 40% RCA and 30% seashore sand shows an optimum replacement value of proportion based on the resistance against the sulphate attack, as its seashore sand particles occupy the small pores in the adhered mortar layer on the surface of the RCA.

COMPARISON OF TEST RESULTS WITH PREVIOUS STUDIES

Compressive Strength

Shanjida A et al. [26] noted that the compressive strength of concrete cylinders steadily declines with a higher proportion of untreated recycled coarse aggregate at 28 days. The weak bond between old mortar and new mortar on the recycled aggregate's surface led to early failure. High water absorption in the mortar adhering to recycled aggregate also contributed to lower concrete strength.

Shin Elizabeth Shaji et al. [27] discovered that substituting natural coarse aggregate with 100% untreated recycled coarse aggregate reduced hardened properties by 15-20%. Adding metakaolin in various percentages by weight of coarse aggregate improved properties by 20-30%. The optimal metakaolin percentage was 10% for M20, M30, and M40, and 7.5% for M50 based on compressive strength.

Naveen Kumar N et al. [8] found that treated recycled aggregate concrete with 50% replacement in M40 concrete achieved higher strength compared to conventional concrete when presoaked in low-concentration acetic acid.

In our project, presoaking recycled coarse aggregate in acetic acid effectively removes adhered mortar, enhancing the quality and physical properties to be on par with natural coarse aggregate. Replacing river sand with seashore sand, which has finer particles, fills the pores of RCA, resulting in a denser microstructure of concrete. This led to a notable increase in the compressive strength of concrete cylinders, particularly with up to 40% replacement of natural coarse aggregate with RCA and 30% replacement of river sand with seashore sand, outperforming the control concrete.

Impact Strength

Naveen Kumar N et al. [8] observed in M40 grade concrete that utilization of treated recycled aggregate (pre-soaking in low concentration acetic acid) with a 50% replacement rate resulted in higher impact strength compared to conventional concrete. Hamzeh Marwan Allujami et al. [28] found that standard recycled aggregate concrete mixtures exhibited reduced impact resistance at all testing ages due to the poor properties of untreated recycled coarse aggregate (RCA). Impact-induced cracking led to failure, with a range of 19-21 at lower RCA levels and 9-12 at higher RCA levels, compared to the range of 21-24 for ordinary natural aggregate concrete (NAC). The addition of MWCNT nanoparticles to RAC significantly improved impact performance by filling the micro and nanopores created by RCA, resulting in high-density concrete capable of absorbing impacts. The current study reveals that replacing up to 30% of the mixture with fine seashore sand particles enhances impact resistance by filling the pores of adhered mortar in recycled coarse aggregate (RCA).

Water penetration

Rajat S. Tembhurne et al. [19] revealed that water penetration levels for M60 .M50 and M40 grade concrete ranged from low to medium permeability, with permeability decreasing as the concrete grade increased. Typically, recycled aggregates increase water penetration levels, but the study showed that the increase was not significant, making recycled aggregates a viable option. Muhammad Fahad Koondhar et al. (2020)

[29] demonstrated that the dosage of recycled aggregates could increase water penetration depth by up to 76% in recycled aggregate concrete. The current research noted that concrete containing 40% treated recycled aggregates without seashore sand had higher permeability compared to the control concrete. However, replacing up to 30% with fine seashore sand particles further reduced permeability by filling the pores of adhered mortar in recycled coarse aggregate, resulting in denser concrete structures.

Sulphate Attack

Compressive strength reduction in concrete, after 58 days of immersion in a 6% MgSO4 solution, reached up to 20% when made with 30% untreated recycled coarse aggregate in relation to control concrete [30]. In the present study, a reduction in compressive strength of up to 12.04% was noted in concrete made with 40% treated recycled coarse aggregate compared to the control concrete after a 30-day immersion in a 5% Na_2SO_4 solution. However, substituting seashore sand (10-30%) filled smaller pores in the recycled coarse aggregate. Additionally, the interaction of cement's C_3A component with chlorides during hydration led to the creation of an insoluble substance known as Friedel's salt. $(3CaO\_Al_2O3\_CaCl_2\_10H_2O)$, which occupied voids in the cement paste., creating a dense microstructure [3]. As a result, this caused a 10.04% reduction in compressive strength and increased the resistance to sulphate attack with up to 30% seashore sand replacement.

Cost Benefit Analysis

Cost comparison for natural aggregates, recycled coarse aggregates, river sand and sea shore sand are given in Table 10. In contrast, for conventional concrete and recycled coarse aggregate concrete mixed with seashore sand, the cost arrived is in Table 11. The preparation cost of 1m^3 conventional concrete is Rs 10932 and recycled coarse aggregate concrete blended with seashore sand is Rs 9528. The cost saving of Recycled coarse aggregate concrete blended with seashore sand is 12.84% higher and also yields better strength and durability properties compared to conventional concrete.

Table 10. Total cost for preparing 2.83 m^3 (100 cubic feet) of coarse and fine aggregates

Aggregate	Labour charges in Rs	days	Rent of Equipment (hammer) in Rs	Transportation and handling charges in Rs	Cost of Acetic acid to treat the recycled aggregates in Rs	Treatment charges (soaking of aggregates in acetic acid) in Rs	Total cost in Rs
Natural coarse aggregate	-		-	-	-	-	7200
Recycled coarse aggregate	3600	3	300	1000	735	300	5935
River sand							37500
Seashore sand	-	-	-	9000	-	-	9000

Table 11. Cost comparison of 1 m^3 of conventional concrete and recycled coarse aggregate concrete blended with seashore sand for M30 grade (1:1.61:2.86)

Quantity	Conventional concrete		Recycled coarse aggregate concrete blended with seashore sand	
	Quantity in kg/m^3	Cost in Rs	Quantity kg/m^3	Cost in Rs
Cement	422	3165	422	3165
River sand	680	5758	476	4030
Seashore sand	-	-	204	411
Natural coarse aggregate	1205	2009	723	1205
Recycled coarse aggregate	-	-	482	717
Total cost	-	10932		9528

CONCLUSION

The paper discusses the results of a research study that explored the impact of simultaneously substituting a portion of natural coarse aggregates with recycled coarse aggregates and replacing river sand with seashore sand at different replacement levels. (0%, 10%, 20%, 30%, 40%, 50% and 100%) on the strength and endurance characteristics of concrete mixtures. The findings of the research program demonstrated the positive impact of partially using recycled coarse aggregates and seashore sand.

Based on the performance of strength tests, such as compressive strength tests on cylinder and impact resistance tests, as well as durability tests, such as water penetration tests under pressure and sulphate attack tests, it was determined that the concrete blend comprising 40% RCA and 30% seashore sand provided the optimal replacement proportion. On the other hand, the concrete mixture with 100% seashore sand replacement exhibited lower strength and durability performance.

Furthermore, the findings demonstrated that treated seashore sand exhibited superior performance compared to untreated seashore sand in terms of quality and properties. The employed treatment techniques notably improved the quality and properties of both recycled coarse aggregates and seashore sand. These treatment methods were proven to be cost-efficient, sustainable, and environmentally friendly recycling practices, rendering them viable for integration into extensive projects.

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REFERENCES

[1] Y. Huang, X. He, Q. Wang, Y. Sun, “Mechanical properties of sea sand recycled aggregate concrete under axial compression,” *Construction and Building Materials*, vol.175, pp. 55–63, 2018, doi: 10.1016/j.conbuildmat.2018.04.136

[2] W. M. Shaban, J. Yang, H. Su, K. H. Mo, L. Li, J. Xie, “Quality Improvement Techniques for Recycled Concrete Aggregate–A Review,*” Journal of Advance concrete Technology,* vol.17, no.1, pp. 151–167,2019, doi: 10.3151/jact.17.151.

[3] S. Minhaj et al., ” Effect of recycled aggregate treatment techniques on the durability of concrete: A comparative evaluation,” *Construction and Building Materials,* vol. 264, no,1, pp. 120284, 2020, doi: 10.1016/j.conbuildmat.2020.120284.

[4] A. J. Tang, “Microstructure and Mechanical properties of concrete with treated recycled concrete aggregates,” *International Journal of GEOMATE*, vol.16, no. 57, pp. 21–27, 2019, doi: 10.21660/2019.57.4537.

[5] H. K. A. Al-Bayati et al., “Evaluation of various treatment methods for enhancing the physical and morphological properties of coarse recycled concrete aggregate,” *Construction and Building Materials*, vol. 112, pp. 284–298, 2016, doi: 10.1016/ j.conbuildmat.2016.02.176.

[6] S. Ismail and M. Ramli, “Engineering properties of treated recycled concrete aggregate (RCA) for structural applications,” *Construction and Building Materials,* vol. 44, pp. 464–476, 2013, doi: 10.1016/ j.conbuildmat.2013.03.014.

[7] L. Wang et al., “An environmentally friendly method to improve the quality of recycled concrete aggregates,” *Construction and Building Materials, vol.* 144, pp. 432–444, 2017, doi: 10.1016/j.conbuildmat.2017.03.191.

[8] N. N. Kumar et al., “Strength properties of Recycled Aggregate concrete treated with Low concentration acetic acid,” *International Journal of Engineering and Technology*, vol.7 pp. 403–406, 2018, doi: 10.14419/ijet.v7i3.12.16115.

[9] M. Ahbilash, “Comparative study on strength of concrete by replacing fine aggregate with sea sand,” *Engineering, Environmental Science, Materials Science*, vol.184, pp. 497–501, 2018.

[10] J. Xiao et al.,” Use of sea-sand and seawater in concrete construction: Current status and future opportunities,” *Construction and Building Materials*, vol. 155, pp. 1101–1111, 2017, doi: 10.1016/j.conbuildmat.2017.08.130.

[11] K. Thunga and T. V. Das, “An experimental investigation on concrete with replacement of treated sea sand as fine aggregate,” *Materials Today Proceedings*, vol 27, no. 2, pp. 1017-1023, 2020, doi: 10.1016/j.matpr.2020.01.356.

[12] V. Mahalakshmi et al*.,* “Experimental Investigation on Concrete Using Sea Sand as Fine Aggregate,” *International Journal of*

Innovative Research in science, Engineering and Technology, vol. 6, no 3, pp. 4456–62, Mar. 2017, doi: 10.1016/j.matpr.2020.01.356.

[13] P. Samraj and V. Nagarajan, “Sea sand as fine aggregate for concrete production,” *National Symposium for Recent Trends in Civil Engineering*, P.S.G college of Technology, Coimbatore. Apr. 2013.

[14] D. A. R. Dolage, M. G. S. Dias and C. T. Ariyawansa, “Offshore Sand as a Fine Aggregate for Concrete Production,” *British Journal of Applied Science & Technology* vol. 3, no. 4, pp. 813–825, 2013, doi: 10.9734/BJAST/2013/3290.

[15] N.P. Ratnayake et al., “Evaluation of the potential of sea sand as an alternative to river sand for concrete production in Sri Lanka,” *Journal of geological society of Sri Lanka,* vol. 16, pp. 109–117, 2014.

[16] A. Hepzibah and M. G. Ranjith Kumar, “Mechanical properties and Durability Properties of Concrete with Partial Replacement of Cement by Hypo Sludge,” *International Research Journal of Engineering and Technology (IRJET),* vol. 6, no.3, 2019.

[17] B. S. Hamad and A. H. Dawi, “Sustainable normal and high strength recycled aggregate concretes using crushed tested cylinders as coarse aggregates,” *Case Studies in Construction Materials*, vol.7, pp. 228–239, 2017, doi: 10.1016/j.cscm.2017.08.006

[18] X. Hung Vu, “Study of the Compressive Strength of Concrete with Partial Replacement of Recycled Coarse Aggregates,” *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7191–7194, 2021, doi: 10.48084/etasr.4162.

[19] R. S. Tembhurne et al., “Strength & Durability Parameter of Recycled Concrete Aggregate,” *International Journal of Science Technology & Engineering*, vol. 5, no. 3, pp. 47–56, 2018, doi: 10.1007/s40069-015-0100-0.

[20] J. Limeira et al., “Mechanical and durability properties of concrete made with dredged marine sand,” *Journal of Construction and Building Materials*, vol. 25, No. 11, pp. 4165–4174, 2011, doi: 10.1016/j.conbuildmat.2011.04. 053.

[21] H. M. Al-Baghdadi, “Experimental study on sulfate resistance of concrete with recycled aggregate modified with polyvinyl alcohol (PVA),” *Case Studies in construction materials,* vol. 14, 2021, Art no. e00527, doi: 10.1016/j.cscm.2021.e00527.

[22] M. Z. Umar and A. F. Mustafa, “The performance optimization of concrete bricks using a sagu fiber,” *SINERGI*, vol. 27, no. 1, pp. 7–14, Feb. 2023, doi: 10.22441/sinergi.2023.1.002.

[23] B T. Ashwini Manjunath et al., “Partial Replacement of Sea and Desert Sand in Place of River Sand for Mortar in Construction, Global Research and Development”, *Journal for Engineering*, vol. 2, Issue 7, pp. 81–85, June 2017, doi: 10.13140/RG.2.2.24600.42242.

[24] F. A. Sanjaya et al., “Analysis of Use Sea Sand as A Fine Aggregate Replacement to Strong Press Concrete,” *International Journal of Engineering, Science & Information Technology*, vol. 1, no. 3, pp. 1–6, 2021, doi: 10.52088/ijesty.v1i3.77.

[25] S. Natarajan, “Experimental Investigations on the Properties of Epoxy-Resin-Bonded Cement Concrete Containing Sea Sand for Use in Unreinforced Concrete Applications,” *Materials*, vol. 12, No. 4, pp 645, 2019, doi: 10.3390/ma12040645

[26] S. A. Shohana, M. I. Hoque and M. H.R. Sobuz, “Experimental investigation on hardened properties of recycled coarse aggregate concrete,” *Advances in Concrete Construction,* vol. 10, no. 5, pp. 369–379, 2020, doi: 10.12989/acc.2020.10.5.369.

[27] S. E. Shaji and J. S. Jithin, “Mechanical Properties of Concrete with Admixed Recycled Aggregate,” *International Journal of Engineering Research & Technology*, vol. 6, no. 6, pp. 1–6, 2018.

[28] H. M. Allujami et al., “Mechanical properties of concrete containing recycle concrete aggregates and multi-walled carbon nanotubes under static and dynamic stresses,” *Case Studies in Construction Materials*, vol.17, Art no. e01651, 2022, doi: 10.1016/j.cscm.2022.e01651.

[29] M. F. Koondhar et al. “Water Penetration of Concrete made with Coarse Aggregates from Demolishing Waste,” *Engineering, Technology & Applied Science Research*, vol. 10, no. 6, pp. 6439–6443, 2020, doi: 10.48084/etasr.3891

[30] M. Arafa et al., “Investigating the Effect of Sulfate Attack on Compressive Strength of Recycled Aggregate Concrete,” *International Journal of Sustainable Construction Engineering & Technology,* vol. 8, no. 2, pp. 66–77, 2017.

[31] A. Nurdini et al., “Building a Prototype of an Eco-friendly House in the Peri-Urban Area,” *Journal of Integrated and Advanced Engineering (JIAE)*, vol. 1, no. 1, pp. 21-28, 2021, doi: 10.51662/jiae.v1i1.9