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Use of Sea Sand as an Alternative to Fine Aggregate in the Construction Industry of Sri Lanka - A Review

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Abstract: River sand is the commonly used fine aggregate for concrete production in Sri Lanka. However, the over-extraction of this resource has caused numerous environmental issues. Globally, sea sand is the most frequently used alternative for river sand. Based on its geography, Sri Lanka has great potential for using sea sand to fulfill the fine aggregate demand in the future. Despite it being used for several large-scale projects in Sri Lanka, sea sand remains underutilized in the local construction sector due to concerns about chloride contamination and impurities such as seashell fragments. This study aims to assess the current utilization of sea sand in Sri Lanka and evaluate the performance of sea sand concrete based on the current literature. A field study was conducted at the Muthurajawela main sand yard, other sea sand distribution sites, and testing laboratories, to understand the current practice. Currently, commercial-scale sea sand mining is carried out by the Sri Lanka Land Reclamation and Development Corporation (SLLRDC). Extracted sea sand is treated to remove the chloride and seashells at the Muthurajawela main sea sand yard. Following the Sri Lankan Standards, various quality control and quality assurance tests, such as water-soluble chloride content, shell content, and particle size distribution, are carried out before releasing sand to the market. This quality testing process ensures that sea sand is suitable for any construction application comparable to the use of river sand and exhibits comparable mechanical and durability performance to river sand concrete, as supported by various studies. According to the SLLRDC data, commercial utilization of sea sand peaked during the post-COVID-19 pandemic period and dropped due to the country's economic downturn. Moreover, using sea sand as an alternative to river sand offers several advantages, including availability on a large scale, which helps mitigate the issues of uncontrolled sand mining and diminishing river sand reserves. Altogether, sea sand presents a technically and economically viable solution for fine aggregate use in the Sri Lankan construction industry.

Keywords: Sea sand, Sri Lanka, Sustainability, Durability, Construction

1. Introduction

River sand, the most widely used fine aggregate in Sri Lanka, is experiencing a critical shortage due to unsustainable extraction practices. The total demand for sand between 2021 and 2025 is estimated to be 55.1 million cubic meters. For 2022, this estimate stands at 9.7 million cubic meters but is expected to increase to 12.4 million cubic meters by 2025 [1]. The Western Province alone consumes nearly 40% of this total demand. Over-extraction has led to significant environmental degradation, scarcity, and escalating costs, prompting an urgent need for sustainable alternatives.

Globally, sea sand is the most frequently used alternative for river sand. The British pioneered using sea sand for concrete production in the 1960s [2], [3]. Today, sea sand is widely used in various regions around the world. Countries like UK, Japan, and China increasingly use sea sand as a primary alternative aggregate [4].

However, the utilisation of sea sand poses certain challenges. Most notably, the presence of chloride ions, which can accelerate corrosion of steel reinforcement, and the presence of seashells and organic matter that may impair concrete performance [5], [6]. Despite these challenges, numerous international and local studies consistently reveal that sea sand has been recommended and found usable for construction purposes after appropriate processing [3], [4], [7], [8].

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Nevertheless, its integration into Sri Lanka's construction industry remains limited, largely due to concerns over quality assurance and a lack of widespread awareness.

This study aims to promote the sustainable use of sea sand as a viable alternative to conventional fine aggregates in construction. It assesses the current utilization of sea sand in Sri Lanka and evaluates the performance of sea sand concrete based on existing literature. A field study at the Muthurajawela main sand yard, distribution sites, and testing laboratories provided insight into current practices. Further, this study discusses the regulations and standards for mining, quality control, and strategies for enhanced performance of sea sand concrete.

2. Current Practices of Using Sea Sand for Construction in Sri Lanka

2.1 Historical Background

Sea sand extraction in Sri Lanka first started back in 1994. It was used to reclaim 400 acres of land in Kerawalapitiya, Muthurajawela. This initiative marked the beginning of dredged sea sand for large-scale land development projects. Dredged sea sand was first employed as an alternative to river sand in 2005, when the Muthurajawela sea sand project was launched. Since then, the Muthurajawela sand yard has become a focal point for sea sand extraction and processing. This project was initiated by heightened demand for construction materials following the devastating Indian Ocean tsunami in December 2004. Extensive reconstruction efforts and planned infrastructure projects such as the Southern Highway and the Colombo-Katunayake Expressway drove this increased need for sand [9].

2.2 Sea Sand Mining

Sea sand mining in Sri Lanka is influenced by seasonal variations, particularly by the southwest monsoon (May to August), which affects sand availability and distribution along the western coast. High wave energy and strong coastal currents during this period can cause severe erosion, sediment transport and siltation, altering sea sand deposits and impacting mining operations [9].

According to the information provided by SLLRDC, the last sea sand mining project used the Cutter Suction Dredger (CSD) method, which is illustrated in Figure 1. This method has the advantage of a higher production rate and the ability to discharge slurry over long distances via pipelines. The dredging process involves lowering suction tubes with a drag head to the seabed, extracting sand mixed with seawater, and transferring it into the vessel's hopper. Once the vessel is fully loaded, it sails approximately 1 km near the shore, where the sand is pumped through floating pipes to the stockpile area using a booster station. The dredging cycle takes around 4 hours, including loading, transporting, unloading, and returning to the mining site. To manage seawater drainage, the Old Dutch Canal has been modified as a receiving pond, and seepage water is discharged through the yard drainage system. Mining operations are carried out continuously, ensuring a steady supply of sand until the required quantity of sand is mined.

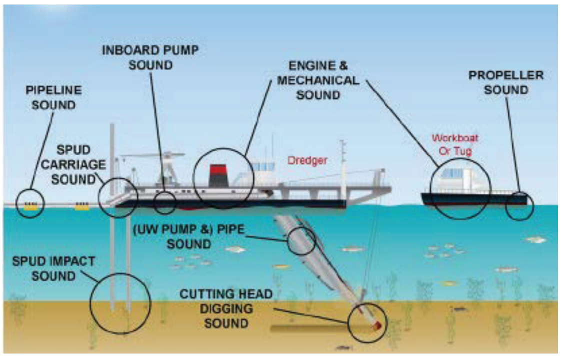

Figure 1 - Schematic view of Cutter Suction Dredger [10]

2.3 Regulations and Standards

The Geological Survey and Mines Bureau (GSMB) is the national body in Sri Lanka responsible for regulating the exploration and mining of minerals, including sand. The GSMB issues licenses for exploration studies and mining activities related to sea sand deposits [9]. Sri Lanka Land Reclamation & Development Corporation (SLLRDC) is the authorized body managing sea sand mining. Mining works are carried out under the guidelines and restrictions from regulatory authorities like the Coastal Conservation Department (CCD) and the Geological Survey and Mines Bureau (GSMB). The CCD does not permit mining at depths ≤15 m; only 1.5 m of the sand layer could be extracted in permitted areas. This restriction mitigates potential negative impacts on coastal erosion and the nearshore sediment budget. Also, the CCD does not allow sea mining within the Coastal Zone (i.e., <2 km towards the sea from the mean low water mark). This regulation protects sensitive coastal ecosystems, infrastructure, and communities. In Sri Lanka, the depth of closure (h_c) is around 10 m, and sand movement due to longshore sand transport occurs at depths less than h_c. Longshore transport usually affects sand movements mainly at depths shallower than h_c. Mining at less than h_c may strongly affect the sediment budget and contribute to beach erosion. The 15-m limit prescribed by the CCD provides a safety margin over h_c to reduce such risks. According to the GSMB, the best sea sand deposits on the west coast have been reported from the Kalutara to Kalpitiya, and these identified sites are shown in Figure 2 [9].

2.4 Sea Sand Processing

Sea sand must be properly processed before its use in construction, as it typically contains impurities such as chloride salts and seashells, which can compromise the durability and structural performance of concrete. Various methods are employed worldwide for sea sand processing. Globally, the most widely adopted methods for processing sea sand involve freshwater washing to reduce chloride content and mechanical sieving to remove coarse shell particles. In Sri Lanka, sea sand processing is primarily carried out at the Muthurajawela main sea sand yard—the country's largest facility dedicated to this purpose. The geographical location of the Muthurajawela sea sand processing yard is shown in Figure 2.

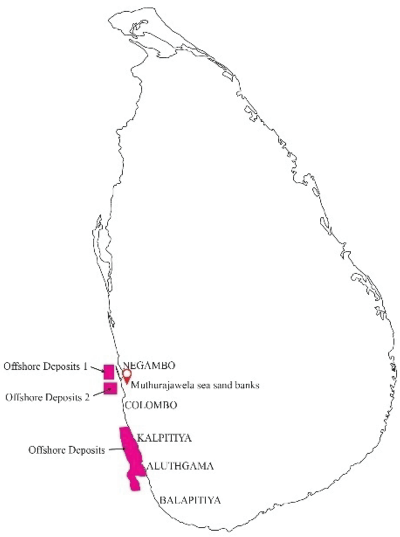

Figure 2 - Geographical location of the Muthurajawela sea sand processing yard and associated sea sand deposit areas along the western coastline of Sri Lanka [11]

Mechanical washing is the mainly used method for sea sand processing. This method effectively reduces chloride levels and removes physical contaminants such as seashells. The sand processing system consists of a vibrating screen, dual wheel rotary cage, a motor, a hopper, belt conveyors, supporting frames, and a mud output pipe. A schematic of the cleaning process is presented in Figure 3, while Figure 4 shows the actual equipment in operation at the Muthurajawela facility.

In practice, raw sea sand is transported daily from stockpile areas to the processing zone. The sand is first loaded into a hopper, from which it is conveyed to a vibrating screen fitted with a 4 mm mesh. Here, continuous freshwater spray is applied to prevent sieve clogging. This initial sieving step ensures the removal of larger shell fragments and oversized particles. These oversized materials—including seashells and particles larger than 4 mm—are separated and conveyed to a dedicated stockpile. The sieved sand is then conveyed to a dual—wheel rotary washing unit for chloride removal.

Upon completion of the washing cycle, the processed sea sand is transferred to a designated stockpile. Samples from this batch are routinely collected and subjected to laboratory testing to verify compliance with national standards for fine aggregates. Only sand that meets these quality benchmarks is released for commercial sale at the Muthurajawela yard.

The rotary washing process also generates a by-product known as offshore sand sludge (OSS), which may contain residual chlorides, fine sediments, organic matter, inorganic compounds, and potentially pathogenic microorganisms. Improper disposal of this sludge, particularly into nearby water bodies, can introduce harmful contaminants into aquatic ecosystems, posing risks to both marine life and human health. Therefore, appropriate treatment and sustainable management strategies for OSS are essential to mitigate its environmental impact [12].

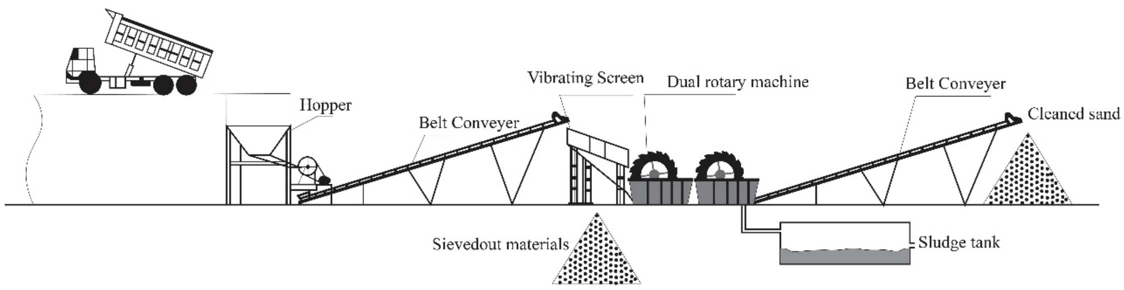

Figure 3 - Sea sand processing system schematic diagram

Figure 4 - Sea sand processing machine at Muthurajawela Sea sand yard

Figure 5 shows sieved-out materials generated during the screening process. This by-product mostly consists of seashells. Seashells are recognized as a valuable secondary resource due to their high calcium carbonate content. They have demonstrated potential for reuse across various industries, including construction (e.g., in cementitious composites), pharmaceuticals, food and dietary supplements, animal feed, and even in the manufacturing of biodegradable plastics. At the Muthurajawela processing yard, the collected seashell by-product is primarily repurposed as a calcium-rich additive for animal feed, particularly for poultry.

Figure 5 - Sieved out material from the sea processing (screening)

2.5 Economic Considerations

When considering the economic benefits, sea sand is often more affordable than river sand, making it an attractive option for construction projects that require a significant quantity of sand. In the Colombo North region, sea sand is more available than river sand. This accessibility can further reduce transportation costs, making sea sand a cost-effective choice. However, transportation costs will increase when using sea sand for construction outside the Colombo area. In those areas outside Colombo, using other alternatives can be more cost-effective. This offers construction managers the opportunity to assess both cost-effectiveness and sustainability when choosing a fine aggregate. Table 1 shows the approximate prices of the main fine aggregate alternatives used in Sri Lanka.

Table 1 - Approximate Prices of main fine aggregate types used in the Sri Lankan construction industry (2024, Source: SLLRDC, Field data: Colombo)

Sand type	Price per 100cft (sand cube)/LKR
River sand	23000-30000
Washed sea sand	16500
Unwashed sea sand	11500
Manufactured sand	15500

2.6 Adoption and Trends in Sea Sand Use

Sea sand mining projects were recently conducted in the 2012/2013 and 2018/2019 periods, and sand mined in the 2018/2019 project is currently being processed for commercial use. SLLRDC plans to start its next mining project by the end of 2025. In the last sand mining project, SLLRDC mined about 4-million-meter cubes of sea sand. Almost 90% of the sea sand mined in the last project was sold out by the end of 2023.

During the past two decades, dredged sea sand has been utilized in various construction projects, including highways and government infrastructure projects. Notable projects are the Colombo-Katunayake Expressway, the Colombo South Harbour Expansion Project, and the Colombo Port City Project. Initially, sea sand was limited to non-structural applications due to concerns about chloride content and impurities. However, advancements in research and processing have enabled the adaptation of sea sand to structural concrete, making sea sand a widely accepted alternative to river sand. Due to the COVID-19 pandemic and government restrictions on river sand mining, the availability of river sand dropped significantly. So, utilization of sea sand increased during that period, as indicated in sales records at Muthurajawela sea sand yard, as shown in Figure 6. After the pandemic, Sri Lanka witnessed the worst economic crisis in its history. The construction sector was also heavily affected by the significantly depleting demand for construction materials, so the demand for sea sand also dropped, reflecting the industry's overall slowdown.

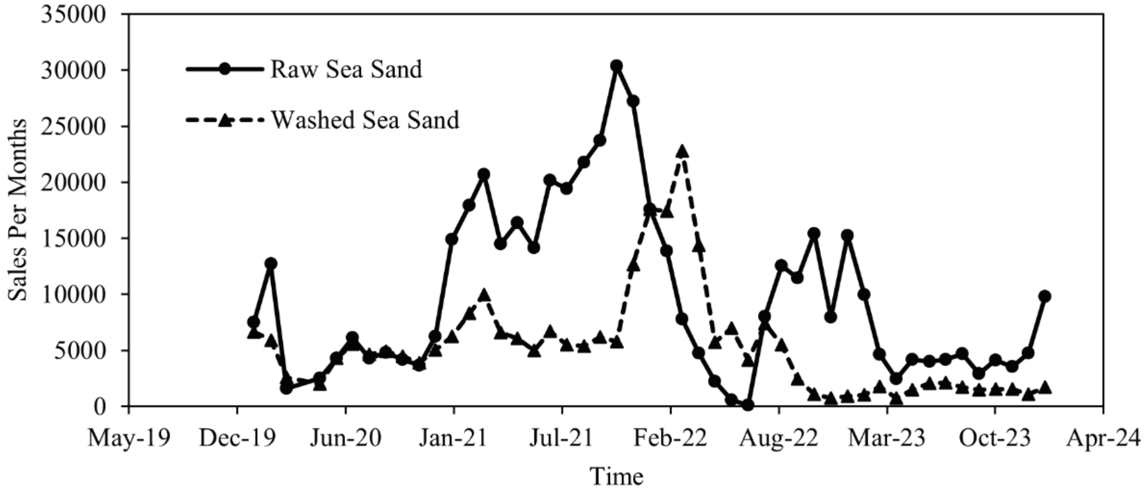

Figure 6 - Monthly washed and raw sea sand sales at Muthurajawela sea sand yard during the 2020 to 2024 period

2.7 Applications of Sea Sand

Currently, treated sea sand is widely used as an alternative for fine aggregate in concrete production. Beyond concrete applications, sea sand has also been used in other applications, including beach replenishment, construction fill and landfill applications, pavement construction, plastering, and the production of construction materials such as bricks. Notable reclamation projects in Sri Lanka, including the reclamation of 400 acres of land in Muthurajawela and the recently conducted Colombo Port City project (Figure 7) used sea sand as a key material.

Figure 7 - Land reclamation using dredged sea sand – Colombo Port City Project[13]

For most non-structural applications, unwashed sea sand can be used, but sieving may be required depending on the application. However, for applications like pavement construction or brick production requirements, untreated sea sand might not fully meet performance standards due to its potential impurities or inconsistent grain size distribution.

3. Quality Assurance and Testing of Sea Sand

In Sri Lanka, several standards and guidelines assess the quality of sea sand for construction purposes. The principal specification is SLS 1397, which sets the requirements for fine aggregates in concrete and mortar. Most of the requirements specified in this standard are derived from BS EN 12620 and BS EN 13139, ensuring alignment with globally accepted performance criteria.

Before releasing sea sand to the market, SLLRDC conducts quality verification to ensure compliance with these standards. Key quality assurance parameters include particle size distribution, water-soluble chloride content, shell content, fines content, water absorption, acid-soluble sulfate, and total sulfur content. These parameters are assessed at regular intervals, with testing conducted weekly or monthly, as outlined in Table 2.

Table 2 - Sea sand quality testing standards and frequencies

Test	Test frequency	Test standard
Aggregate size and grading	Weekly	BS EN 933-1 :1997 + A1 :2005
Specific gravity	Monthly	BS EN 1097-6: 2013
Water absorption	Monthly	BS EN 1097-6: 2013
Shell content	Monthly	SLS 1397: 2010
Water-solublechloride	Weekly	BS EN 1744-1: 1998
Acid-soluble sulfate	Monthly	BS 1744-1: 1998
Total Sulfur content	Monthly	BS EN 1744-1: 1998
Fines content	Weekly	BS EN 933-8

Testing is primarily conducted at the Engineering Materials Testing (EMT) Laboratory of SLLRDC weekly on samples taken from the Muthurajawela washing facility. Third-party evaluations are performed monthly by the National Building Research Organization (NBRO) to maintain independent quality validation. Samples are collected from each batch of washed sand at multiple depths for a representative evaluation. In cases where test results do not meet the prescribed standards, the sand undergoes additional washing procedures before being approved for distribution.

This chapter further discusses the limit values and testing methods, and quality control for key parameters, including water-soluble chlorides, seashell content, and grading.

3.1 Chloride Standards and Limits

Different standards provide a framework for ensuring concrete durability against chloride in concrete. UK has incorporated the limit values of chloride content in marine aggregates, including dredged marine sand, into the British Standard BS 882 as shown in Table 3 and Table 4.

Table 3 - Limits for chloride content of aggregates (BS 882:1992 Table 8 Appendix C)[14]

Type and use of concrete	Cl^-/%
Prestress concrete and heat-cured concrete containing embedded metal	0.01
Concrete containing embedded metal made with cement complying with BS 4027	0.03
Concrete containing embedded metal and made with cement complying with BS 12, BS 146, BS 1370, BS 4246, BS 6588, BS 6610 or combinations with ground granulated blast-furnace slag (GGBS) or pulverized-fuel ash (PFA)	0.05
Other concrete	No limit

Note: The chloride ion content (Cl^-/%) is expressed as a percentage by mass of chloride ions of the combined aggregate.

Table 4 - Limits of chloride content of concrete(BS5328: 1997-Table 6.4)

Type and use of concrete	Cl-/%
Prestress concrete and heat-cured concrete containing embedded metal	0.01
Concrete containing embedded metal made with cement complying with BS 4027	0.02
Concrete containing embedded metal and made with cement complying with BS 12, BS 146, BS 1370, BS 4246, BS 6588, BS 6610 or combinations confirming to 5.4.1	0.04
Other concrete	No limit

Note: The maximum total chloride content (Cl-/%) is expressed as a percentage of chloride ion by mass of cement.

BS 882 defined the guidance limit for combined aggregate (coarse and fine aggregate combined in the proportion to be used in the concrete). The limit defined varies depending on the use of concrete. These guidelines are based on the assumption that aggregates are the sole contributors to chloride content. Therefore, adjustments may be needed to account for chlorides present in cement and admixtures. The European Union (EU) has adopted British standards as European standards. BS 5328 was replaced with BS EN 206 (Table 5), and BS 882 was replaced with BS EN 13139 and BS EN 12620.

Table 5 - Chloride limits BS EN 206:2013

Concrete use	Chloride content class	Maximum CP content by mass of cement %
Not containing steel reinforcement or other embedded metal with the exception of corrosion- resisting lifting devices	Cl 1.0	1.00
Containing steel reinforcement or other embedded metal	Cl 0.20	0.20
	Cl 0.40	0.40
Containing prestressing steel reinforcement in direct contact with concrete	Cl 0.10	0.10
	Cl 0.20	0.20

Under BS EN 206, limit values of maximum chloride content in the concrete are defined by the mass of the cement. There is no limit for coarse aggregate according to the BS EN 126020. EN 13139 has defined a guidance limit for fine aggregate considering the weight percentage of aggregates. In the Sri Lankan context, SLS1397:2010 defined the chloride limit for fine aggregate, restricting it to a maximum of 0.01% by mass. This conservative threshold reflects prevailing concerns within the local construction industry regarding the potential durability risks associated with the use of sea sand, particularly in reinforced concrete applications. By enforcing such a low permissible chloride level, the standard aims to instill user confidence and ensure that the incorporation of sea sand does not compromise the long-term performance and structural integrity of concrete.

3.2 Methods for Chloride Control

Sri Lanka's *National Policy on Sand as a Resource for the Construction Industry* suggests that chloride reduction can be achieved by either stockpiling sea sand and allowing natural rainfall to leach out the chlorides over several months or by mechanical washing [15].

As evidenced by multiple studies conducted in Sri Lanka, natural rainfall serves as an effective natural mechanism for reducing chloride levels in sea sand [7], [16]. Long-term monitoring of stockpiles at the Muthurajawela site has demonstrated that prolonged exposure to monsoonal rainfall can substantially lower chloride concentrations [17], [18]. Specifically, studies have shown that one to two years of natural washing by monsoon rains is sufficient to reduce chloride levels in sea sand stockpiles, even those exceeding 30 meters in height, to levels acceptable for concrete use [12], [19], [20].

Experimental studies, such as the "Sand Column Test," have demonstrated the effectiveness of simulating rainfall in reducing chloride levels. Even a low rainfall of 80 mm was found to reduce chloride levels in sea sand to below acceptable levels. The same study simulated higher rainfall (320 mm), which is the highest rainfall that can be expected around the Muthurajawela stockpile area, and found that chloride can be removed totally, but still, a certain amount of chloride is not draining out at the bottom of the stockpile due to capillary action [21].

While natural washing is beneficial, relying solely on rainfall introduces variability and may not guarantee compliance with strict national standards, particularly considering quality assurance for large stockpiles. Capillary effects and uneven moisture distribution can result in non-uniform chloride removal across the depth of stockpiles, indicating the need for a more reliable process.

Mechanical washing, described in Section 2.4, offers a more controlled and efficient method of chloride removal [18], [22]. Washing facilities at Muthurajawela consistently reduce chloride concentrations to levels compliant with the national standard of 0.01% by mass as presented in Figure 8. Sand released from this facility for commercial distribution is verified to meet this durability requirement. However, the approach is not without drawbacks. Mechanical washing requires substantial freshwater input and incurs significant operational costs, posing sustainability and economic concerns for widespread adoption.

3.3 Chloride Content Testing Methods

The chloride content of the sea sand is continuously monitored since it is the primary concern with sea sand concrete durability. Two test methods are used to determine the water-soluble chloride content in sea sand, which are the Silver Nitrate Method and the Phot 46 palin test 7100 method.

3.3.1 Silver Nitrate Method

The water-soluble chloride content is determined using the Silver Nitrate method (BSEN 1744-1:1998 method). The chemical reaction between silver nitrate ($AgNO_3$) and chloride ions (Cl^-) forms a silver chloride precipitate (AgCl). Then, the resultant AgCl precipitate was titrated to calculate the excess $AgNO_3$ using a Potassium Thiocyanate solution and an Ammonium Iron (III) indicator. The completion of the reaction is indicated by the first permanent color change from white opalescence to pale.

$$AgNO_3 + Cl \longrightarrow AgCl + NO_3 \quad \text{... (1)}$$

$$AgNO_3 + KSCN \longrightarrow AgSCN + 2KNO_3 \quad \text{... (2)}$$

3.3.2 Photo 46 Palintest 7100 Method

The Palintest Chloridol Test is based on a tablet reagent system containing silver nitrate. Chloride reacts with silver nitrate to produce insoluble silver chloride at the chloride encountered in the test. The insoluble silver chloride is observed to be turbid in the sample. The degree of turbidity is directly proportional to the chloride concentration and is measured using the palintest photometer.

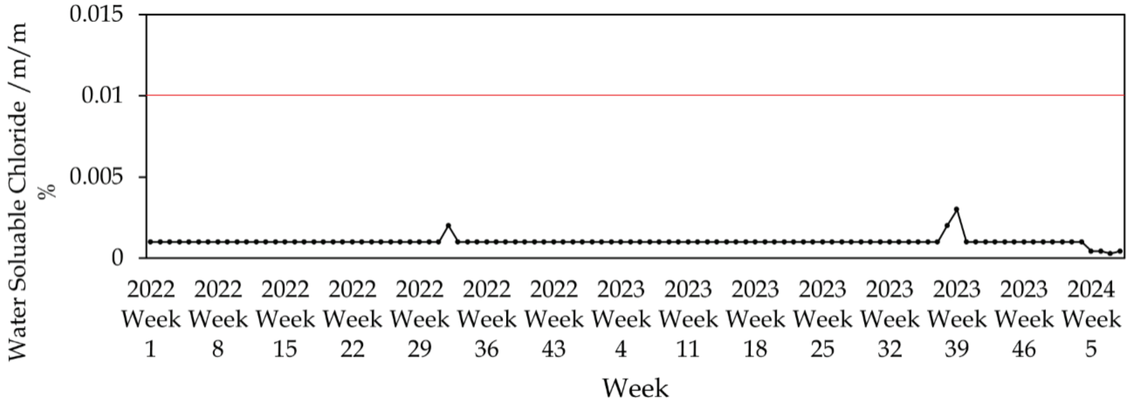

Figure 8 - Water soluble chloride content variation of Muthurajawela sea sand during the 2022 - 2024 period (Source: SLLRDC)

3.4 Shell Content Standards and Limits

Limits of shell content in different regions and standards are shown in Table 6. This reveals significant variations in shell content limits for construction aggregates across regions, reflecting local material properties and practices. The British standards set limits based on size, while the British/EU standard considers application type. Sri Lanka allows up to 15% for a 0.5 - 8 mm size range by mass of the sand, so it has a higher limit for shell content than other standards.

3.5 Seashell Content Control

Removing seashells from sea sand, particularly larger fragments, is typically carried out through mechanical or manual processing methods such as sieving. The sieving procedure implemented at the Muthurajawela processing facility, detailed in Section 2.4, has proven effective in significantly reducing the residual shell content. As illustrated in Figure 9, the shell content of sea sand released to the market from Muthurajawela between 2022 and 2024 remained consistently below 3%, which is well within the acceptable limit (15%) defined by Sri Lankan standards.

3.6 Testing Shell Content

The method given in SLS 1397:2010 Appendix B is followed to determine the shell content in the fine aggregate. This method is similar to the method given in the literature [17]. This method separates the fraction of fine aggregate passing an 8 mm sieve and retained on a 500 µm test sieve. A weighted fraction of around 50 g is treated with hydrochloric acid, and the dried residue is weighed when cool. The difference between the original weighted portion and the oven-dried sample is taken as the shell content of the sample.

3.7 Particle Size Distribution and Grading

Previous studies have highlighted that sea sand grading characteristics can vary depending on geographic origin along the Sri Lankan coastline. It can range from the coarser Zone C to the finer Zone F according to BS 882 limits, as shown in Figure 10 [6], [23]. Due to this variability, it is imperative to perform grading assessments before the commercial release of sea sand for construction purposes. The particle size distribution is typically evaluated following BS EN 933-1, which outlines standardized procedures for determining aggregate size fractions through sieve analysis.

Table 6 - Limits for shell content in different regions [24]

Region	Code	Application	Limit %	Comment
British	BS 882: 1983	5- 10 mm	20	By aggregate
	BS 882: 1992	≥ 10 mm	8	By coarse aggregate
British/European Union	BSEN 12620-2013	SC10	<10	
		SCNR	No requirement	
British/European Union	BSEN 12620-2013 CI 0.20	SC10	≤10	
		SC Declared	≥10	
		SCNR	No requirement	
Sri Lanka	SLS 1397:2010	0.5-8 mm	≤15	By sand

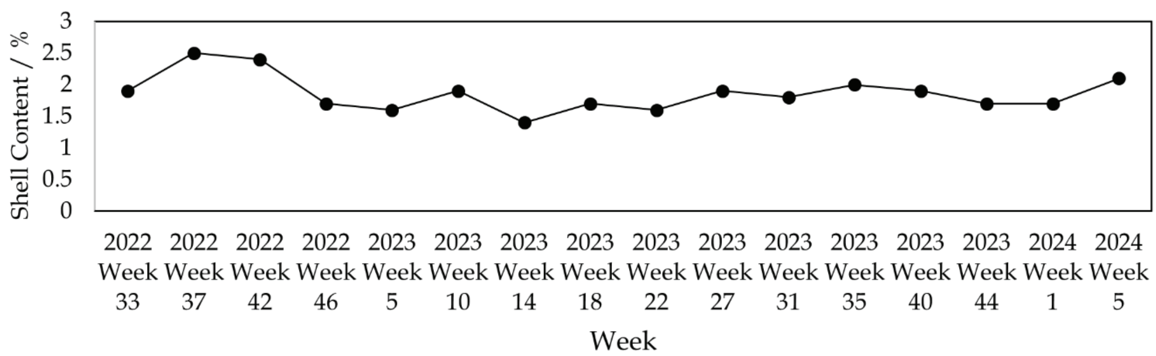

Figure 9 - Shell content variation of Muthurajawela Sea Sand during the 2022 -2024 period (Source: SLLRDC)

Dolage et al. [6] conducted a study on sea sand samples sourced from the Muthurajawela stockpiles and reported a median particle size (D_{50}) of around 0.6 mm, which is considered very appropriate for concrete production. Similarly, Rathnyaka et al. [20] analyzed sea sand from various stockpiles within Muthurajawela, finding D_{50} values ranging from 419 μm to 896 μm(medium sand to coarse sand), with sorting from very well sorted to moderately well sorted. However, particle size distribution data for processed sea sand from Muthurajawela conform to the gradation limits outlined in BS EN 12620, with D_{50} values generally ranging from 0.4 to 0.5 mm, indicating a slightly finer grading consistent with standard requirements for concrete aggregates.

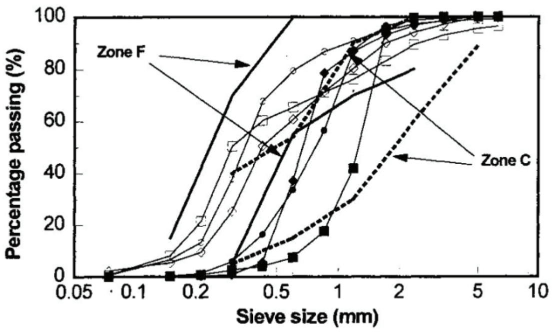

Figure 10 - Particle size distribution of sea sand collected from various locations along the Sri Lankan coastline

4. Fresh and Hardened Properties of Sea Sand Concrete

Sea sand concrete (SSC) presents unique fresh and hardened properties that distinguish it from conventional concrete made with river sand and freshwater. The mineral composition of sea sand is comparable to that of river sand, providing a similar foundational structure [25]. Existing literature presents conflicting conclusions regarding its workability, strength, and durability.

4.1 Workability

Sea sand concrete presents unique workability characteristics influenced by its composition, particularly the presence of shell fragments and the smooth texture of sea sand particles [8]. Literature suggests that seashells present in the sea sand can negatively impact workability due to their elongated nature and irregular shapes of shell particles [26]. However, this adverse effect of shell content can be offset by the relatively smooth surface texture of sea sand, which reduces particle interlocking and enhances flowability [21].

Most studies show that its workability is comparable to ordinary concrete with minimal impact on slump values [7], [26], [27]. However, conflicting findings exist in the literature, with some researchers reporting a decrease in workability as the sea sand content increases [4], [28]. Some researchers suggest that the difference in workability is often attributed to differences in the seashell content within sea sand. Generally, a higher proportion of seashells is associated with reduced workability, as they create a less cohesive mix and increase water demand [29], [30], [31], [32]. In Sri Lankan practice, as we discussed in the previous chapter, standard sea sand processing involves the removal of larger shell particles exceeding 4 mm. This ensures that the final shell content remains within the acceptable limits set by local standards, minimizing any significant adverse effects on workability.

4.2 Compressive Strength

Several research experiments have studied the compressive strength of sea sand concrete in the Sri Lankan context, with research yielding varying conclusions. These inconsistencies are primarily due to differences in sea sand properties, including particle grading, salinity levels, and shell content, as well as variations in mix proportions used across different studies. In general, the compressive strength of sea sand concrete can be comparable to or slightly lower than that of conventional concrete made with river sand [7], [33].

Research done by Ratnayake et al. [23] found that the concrete produced using sea sand, using samples from different ages of stockpiles (allowed only for rainfall), had a compressive strength of 30-40 N/mm^2, as shown in Figure 11, which falls within the limits of conventional concrete.

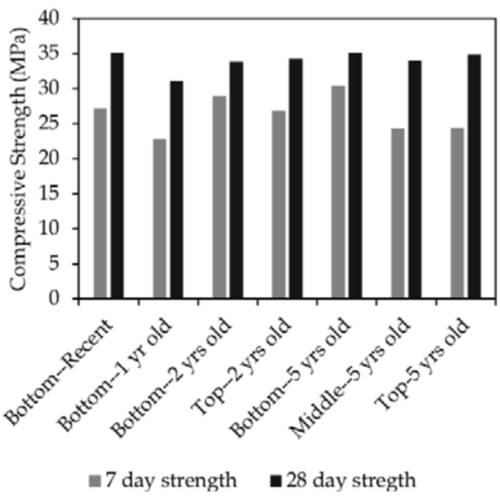

Figure 11 - Compressive strength of concrete made with sea sand from various stockpiled locations (Top, Middle, Bottom) and ages[20]

Research done by Dias et al. [21] has studied the performance of sea sand for concrete mix design. The experiment was conducted for grades 20, 25, and 30 and tested at 3,7, and 28 days, as shown in Figure 12. The results inferred that the concrete mixed with sea sand performed satisfactorily in terms of strength based on the mentioned testing procedures.

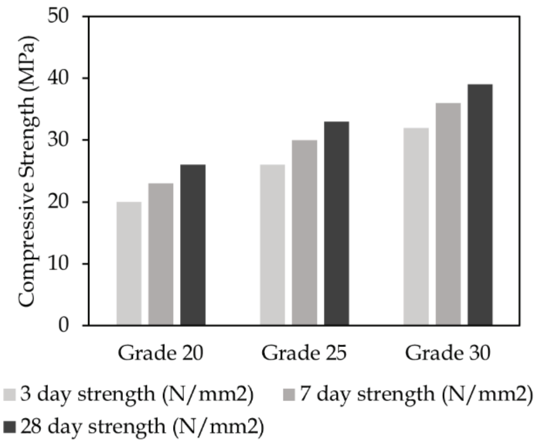

Figure 12 - Concrete mix design results (sea sand as fine aggregate) [21]

Mahendran et al. [33] conducted experiments to assess the suitability of using sea sand to replace river sand in concrete. Their findings indicated that concrete mixes containing 50% and 100% sea sand exhibited lower compressive strength than concrete made with 100% river sand, as shown in Figure 13. The study concluded that washed sea sand is suitable for concrete and plastering applications. However, the complete replacement of river sand with sea sand decreases compressive, split tensile, and flexural strengths.

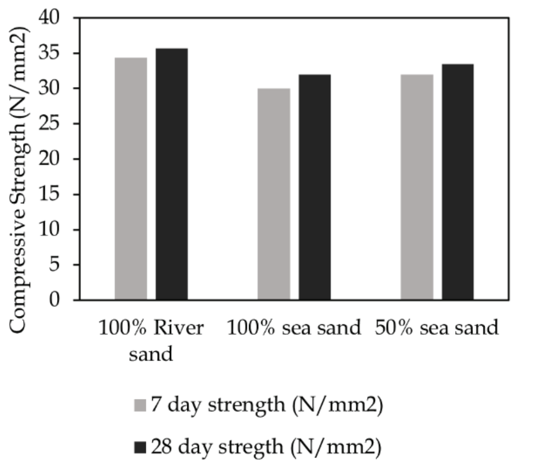

Figure 13 - 7-day and 28-day compressive strength [33]

Despite these variations, it is evident that sea sand, when subjected to appropriate processing and quality control, can produce concrete with mechanical properties comparable to river sand-based concrete [7], [16].

Also on the global scale, research supports the notion that the sea sand concrete with properly washed sea sand is capable of achieving similar or even higher early-age compressive strength, while long-term strength may sometimes be marginally lower [3], [34], [35], [36]. These limitations can be effectively mitigated through strategies such as optimizing mix proportions and incorporating supplementary cementitious materials (discussed in Section 6.2) [37], [38].

4.2.1 Influence of shell content on mechanical properties

The impact of seashells on concrete's mechanical properties appears complex and dependent on several factors. Previous studies indicate that shrinkage increases as the shell content in sea sand increases [25]. Studies like [30], [39] suggest minimal to slight reductions in compressive strength with moderate seashell content (10-29%). However, others report significant decreases at higher replacement levels (50% or more) [40], [41]. Interestingly, [42] observed an initial strength increase with small seashell additions, followed by a drop with more significant amounts. This suggests an optimal content range for strength. The angular shape and size variations of seashells compared to traditional aggregates can negatively affect strength, according to [42]. Also, seashells can be a viable partial replacement for aggregates, but careful consideration of content, processing, and mix design is crucial to maintaining acceptable mechanical properties in concrete [30], [39]. As discussed in Section 3.5, sea sand pre-processing at Muthurajawela controls the seashell content below 3%, mitigating the negative impact associated with high shell contents.

5. Durability Performance of Sea Sand Concrete

As an alternative to river sand for concrete production, sea sand presents a challenge in its unprocessed form due to factors like the potential for high chloride content and the presence of shells and other impurities [4]. The presence of chloride ions can trigger corrosion in steel reinforcements, thereby impacting the durability of concrete structures. Proper treatment methods can significantly enhance its properties, reduce the chloride content, and remove impurities, allowing for improved durability and longevity in concrete applications while mitigating issues related to corrosion and material degradation.

5.1 Influence of Chloride on the Durability of Sea Sand Concrete

The presence of chlorides in sea sand is the main concern regarding the durability of sea sand concrete. It can lead to corrosion of steel reinforcements within the concrete over time [3], [23]. Once the chloride ions penetrate the concrete and reach the embedded steel reinforcement, they disrupt the passive oxide layer and initiate the electrochemical corrosion process. Figure 14 illustrates this electrochemical process of steel bar corrosion.

A study by Su et al. [43] on the corrosion efficiency of sea sand on steel bars revealed that chloride in the sea sand can react with the aluminium phase product in cement to generate FS salts. These salts reduce the resistance between the cathode and anode, thereby improving the corrosion efficiency and accelerating the electrochemical degradation of steel bars. Similarly, research done by Andreamisa et al. [44] also found that the corrosion rate of steel bars is directly proportional to the chloride ion concentration.

Beyond reinforcement corrosion, chloride ions also influence cement hydration, altering the microstructure and mechanical properties of concrete. According to Ge et al. [45], chloride ions react with hydration products to form compounds with larger volumes and lower strengths, which are seen as flocculent substances at the micro level. They compromise the internal integrity of concrete and accelerate crack propagation, thereby reducing the overall compressive performance of concrete. Therefore, the durability of sea sand concrete is contingent on maintaining the chloride content within acceptable limits.

Research done by Dias et al. [21] using grade 20 concrete has established that 0.075% by weight of sand is a safe limit for the allowable chloride ion content in sea sand for reinforced concrete in Sri Lanka. To achieve this threshold, chloride reduction can be effectively carried out by either washing sea sand naturally or mechanically. As highlighted in section 3.2, the processing and cleaning at Muthurajawela successfully reduces chloride to below 0.01%, ensuring compliance with national standards and literature-based recommendations.

5.2 Influence of Shell Content on the Durability of Sea Sand Concrete

Seashells appear to offer both positive and negative effects on durability. Their low porosity can significantly enhance water resistance and permeability [42]. This aligns with the observation that seashell content can improve the resistance to freeze-thaw cycles in some cases [30]. However, the presence of organic matter and the inherent fragility of some seashells can weaken this resistance. Furthermore, the irregular shapes of seashells can negatively impact the workability of sea sand concrete [25]. This can lead to difficulties in mixing, placing, and compacting the concrete, potentially resulting in an inconsistent final product with compromised strength and durability. The elongated nature of shell particles can hinder the smooth flow and proper compaction of the concrete mix, making it challenging to achieve the desired consistency and uniformity [46].

As highlighted in Section 3.4, seashell content after sea sand cleaning remains well below the national standard limits. However, small seashell fragments are still present in the sea sand, which is a concern for most local contractors. Further research is necessary to assess the long-term durability of smaller shell fragments on the durability of sea sand concrete.

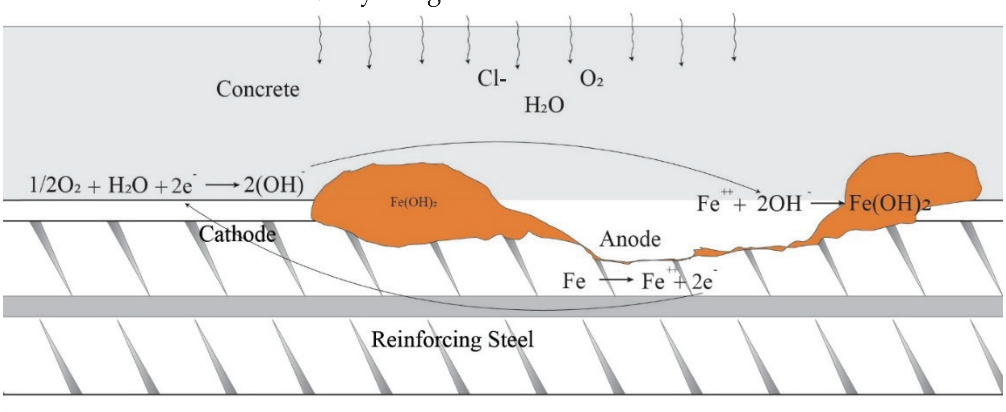

Figure 14 - Schematic diagram of steel reinforcement corrosion in a chloride environment

6. Blended Sea Sand Concrete

Blending sea sand with other types of sand, such as manufactured sand (M-sand) and river sand, and using supplementary cementitious materials (SCMs) offers a potential solution to challenges using sea sand solely for concrete. This chapter reviews the performance of concrete when sea sand is blended with other types of sands and SCMs, focusing on various mechanical and durability properties.

6.1 Blended Sea Sand and Manufactured Sand Concrete

Studies have investigated the blending of manufactured sand (MS) with sea sand as a viable alternative to river sand. This approach aims to balance the properties of these alternative fine aggregates and provide an economical and sustainable solution [26], [47], [48]. Manufactured sand typically has higher angularity and surface roughness compared to the smoother, more rounded particles of sea sand. These distinct particle characteristics have contrasting effects on material performance, and blending these sands has been shown to mitigate the limitations inherent in each type [26].

Arulmoly et al. [48] have studied blending manufactured sand with sea sand using cement mortar. Their research concludes that blending manufactured sand with sea sand at a 25% replacement level is the most feasible solution based on workability, flexural strength, and compressive strength. Lower replacement levels with sea sand increased the wet and dry bulk densities of mortars. Blending generally improved workability without significantly impacting consistency or initial setting time, but increased bleeding and decreased workable life. Water retentivity improved significantly at 25% and 50% MS content. Lower replacement levels also enhanced flexural strength, compressive strength, and capillary water absorption.

Pranavan and Srinivasan investigated the behaviour of concrete using manufactured sand (MS) and sea sand (SS). They found that fully SS-based concrete showed the highest compressive strength compared to fully MS-based concrete and a 50/50 blend at 28 days. However, fully MS-based concrete had the highest split tensile strength compared to fully SS-based and the blend. The 50/50 blend exhibited the highest flexural strength compared to MS-based and SS-based concrete. This research recommended the use of SS as an alternative fine aggregate [49].

Based on the literature, the optimal blend ratio depends on the target properties (workability, strength, durability). Furthermore, blending sea sand and manufactured sand provides a more eco-friendly and cost-effective solution for the Sri Lankan construction industry.

6.2 Sea Sand and Supplementary Cementitious Materials

Supplementary cementitious materials (SCMs) are widely recognized for their capacity to enhance the performance and sustainability of concrete, including seawater sea sand concrete (SSSC) [5], [50], [51]. Several SCMs are commonly used in SSSC systems, including granulated blast furnace slag (GGBS), metakaolin (MK), fly ash (FA), and silica fume (SF) [8].

SCMs can enhance early compressive strength and improve the long-term mechanical performance of sea sand and seawater concrete, particularly when used in optimal proportions [51], [52]. Workability is influenced by both the type and dosage of SCMs, requiring careful mix design to balance flow and strength [5], [53].

SCMs improve SSSC durability performance through various mechanisms. SCMs promote pozzolanic and latent hydraulic reactions. Their active components (Si and Al) react with calcium hydroxide (CH) produced during cement hydration, forming additional calcium-silicate-hydrate (C-S-H) gel, which is the primary binding phase in concrete [5]. High-aluminum SCMs, such as MK and GGBS, improve the chloride binding capacity. This often involves the formation of chloride-containing hydration products like Friedel's salt and hydrocalumite, which reduces the amount of free chlorides in the concrete pore solution [8], [50], [54]. Microstructural analyses further reveal that the fine particles of SCMs act as fillers and nucleation sites for hydration products, promoting the formation of a denser and more refined pore structure. This refinement reduces the permeability and improves long-term performance [5], [50], [51]. For instance, adding 5% MK decreased the total porosity of seawater concrete by about 12%, reducing large pores and increasing small pores. Similarly, nanosilica significantly reduced total porosity [8].

A study by Zhenlin Li et al. [52] found that adding SCMs like fly ash can reduce early-age shrinkage, while LC2 may increase self-shrinkage and enhance strength development after the first day. The proportion of fine pores (<50 nm) is a key factor in controlling shrinkage and cracking potential, and SCMs help optimize this pore structure.

Furthermore, SCMs facilitate the use of sea sand without extensive pre-processing, which reduces reliance on fresh water typically required for mechanical washing. Also, it enables the use of seawater in sea sand concrete, making concrete production more feasible in regions facing freshwater and river sand shortages [5], [8]. The improved durability and reduced permeability make SCM-based sea sand concrete suitable for marine and coastal infrastructure, where long-term exposure to aggressive environments is a critical concern [50].

7. Conclusions and Recommendations

This paper presents findings on the current utilization of sea sand in the Sri Lankan construction industry and evaluates the performance of sea sand concrete based on the existing literature in this study area. Based on the findings, the following conclusions and recommendations can be made.

The over-extraction of river sand in Sri Lanka has led to environmental issues, necessitating the exploration of viable alternatives, such as sea sand, for fine aggregate in concrete production.

Sri Lanka has a high geographical potential for using sea sand, and research suggests that it is a feasible and cost-effective option for the construction industry.

It is essential to ensure that the sea sand going out after the processing meets standard quality requirements, such as grading, chloride content, shell content, etc. Quality assurance tests conducted by SLLRDC and NBRO confirm that properly treated sea sand is suitable for any construction application in Sri Lanka.

Research findings suggest that sea sand concrete may have marginally lower compressive strength than river sand concrete, especially in the long term. However, the variation in strength is not significant enough to compromise its structural integrity, and any limitations can be effectively mitigated through strategies such as optimizing mix design and the use of SCMs.

Chloride contamination is a key concern for the durability of sea sand concrete. However, the washing process at Muthurajawela effectively reduces chloride content to acceptable levels, ensuring that washed sea sand can be used without compromising durability.

The presence of seashells offers both positive and negative effects on durability. Further studies are necessary to evaluate the performance of sea sand with seashell fragments smaller than 4 mm.

Incorporating blended sand can optimize the strength and durability of sea sand concrete, offering a sustainable and cost-effective solution for the Sri Lankan construction industry.

The strategic use of supplementary cementitious materials like silica fume, fly ash, and GGBS can further improve sea sand concrete/sea water sea sand concrete (SSSC) durability, strength, and overall performance, making it more resilient to marine environment considerations.

Future research shall be focused on integrating Seawater Sea Sand Concrete (SSSC) into the Sri Lankan construction industry as a sustainable solution to minimize reliance on freshwater resources.

To facilitate broader acceptance, targeted awareness programs are recommended to educate industry professionals/ contractors on the viability of sea sand. Developing the distribution network of sea sand can improve accessibility and cost efficiency, further encouraging its use in the construction sector.

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