EVALUATING THE CHEMICAL CHARACTERISTICS OF SEA SAND CONCRETE

S. SELVAKUMAR[1]

Research Scholar, Department of Civil and Structural Engineering,

Annamalai University, Annamalainagar – 608 002.

Email : selva.phd2020@gmail.com

G. SRINIVASAN[2]

Associate Professor, Department of Civil and Structural Engineering,

Annamalai University, Annamalainagar – 608 002.

Email: Drgs72@gmail.com

Corresponding author Mail id: selva.phd2020@gmail.com

Abstract

Sea sand is a more easily accessible sort of sand than river sand. Sea sand is not frequently used since it could contain hazardous materials. Sea sand might be used to either address the existing problems with concrete's strength and durability or provide an excellent substitute for river sand, which is seriously endangered due to excessive use of excavation techniques in almost every country on the planet. This investigation was limited to fine aggregate only. Sand is used as a fine aggregate in concrete and is a crucial part of engineering projects. One such easily obtained substitute that is already in use in coastal areas is sea sand. There are several places where sea sand is gathered, such as Parangipettai, Killai, Kollidam, and Kodiyambalaiyam. In this study, sea sand is used as a fine aggregate to investigate its chemical properties. Physical characteristics such as specific gravity and sieve analysis were determined in this investigation. The EDS of river and sea sand was also examined. The percentage of sand retained on each screen is typically displayed in a sieve analysis, which is the output of the sieve analysis of sand. With the use of this information, the particle size distribution of the sand may be ascertained and it can be categorised using accepted grading guidelines. Because of its chemical makeup, sea sand is mainly employed as a fine aggregate in concrete.

Keywords: sea sand, specific gravity, chemical properties, chloride and sulphide content.

1. Introduction

India is suffering from a severe river sand deficit, which has forced imports. India is thought to generate an average of 502 million tonnes annually to satisfy industrial needs. The amount of river sand being used is around eight times this. The main issue here is that not all river sand is created in legitimate mining. Not only this but states like Kerala only have a tiny number of resources for their riverbeds. Although utilising sea sand offers many benefits, there are still a few environmental effects that need to be taken into account. The dredging of the sea sand may damage local plant and animal life. This research anticipates advancements in the industry and lays the way for the use of a range of non-traditional materials as fine aggregates in concrete, which can either completely or partially replace conventional concrete.

Physical characteristics such as specific gravity, fineness percentage, and solubility were measured in both treated and untreated sea sand. The study's findings show that the treated sea sand's chloride content is less than the permissible threshold of 0.075 percent weight of sand [1]. Utilising certain industrial waste provides several benefits for the building industry in terms of cost and the sustainability of natural resources, claims [2]. Greater amounts of fine aggregate are required for the creation of concrete. As a result of this increase in utilisation as indicated in [3]. Concrete is the most widely used man-made commodity worldwide. It ranks second to water as the substance that is utilised the most in the globe. Concrete is generally inexpensive, durable, and long-lasting. Concrete is especially important in densely populated emerging countries like China and India. Annually, 11.5 billion tonnes of concrete are needed [4].

[5] Natural sea sand and seawater are gaining more and more attention from researchers throughout the world as sustainable substitutes for traditional concrete manufacturing that uses river sand and freshwater as stated in [6] and causes environmental damage and resource shortages. [7] Sea-sand concrete, however, can corrode steel reinforcing bars and cause the building to become less sturdy. Impressed current cathodic protection (ICCP) may successfully prevent re-bar corrosion, and attaching carbon fibre mesh to RC structures can help the damaged structures hold additional weight.

[8] Concrete that has been mixed with saltwater may be more sustainable. However, saltwater with high chloride levels has the ability to erode steel reinforcement. The dynamic vapour sorption (DVS) test provides data on pore structure using an experimental setup to assess the equilibrium between the bulk water content of the specimen and the relative humidity (RH), at a constant temperature [9]. According to [10], the economy and the environment may benefit significantly from the use of sea sand and seawater in concrete construction. However, the use of sea sand (SS) and SW in concrete is rather limited in commercial practice due to a lack of knowledge about the properties of the mixture.

[11] Making concrete requires extensive natural gravel and sand mining, which has led to severe resource and environmental issues. [12] Because fibre-reinforced polymer (FRP) bars and saltwater sea sand concrete (SWSSC) are better suited to marine settings than traditional concrete and steel reinforcements, they are being used more frequently in the construction of maritime infrastructure.

In a study by [13], the mechanical, transport, and chloride binding properties of ultra-high-performance concrete (SWSS-UHPC) based on seawater and sea sand with supplemental cementitious materials (SCM) (silica fume and slag) were investigated. Aggregates from different sources and up to 62.5% SCM were used to create mixtures. This work examines the mechanical properties of SWSSRAC, or recycled aggregate concrete with sea sand and saltwater [14]. To find out how varying water-to-cement ratios, curing ages, and RA replenishment rates affected the mechanical properties of the SWSSRAC, a total of eighteen mix ratios were built.

2. Materials and methods

2.1 Sea sand

The very low chloride content of the sea sand utilised in this experiment complies with Indian standard Codal Provisions. Along a 245 km stretch of coastline in Tamil Nadu, India, lie the districts of Villupuram, Cuddalore, and Nagapattinam. Four locations—Parangipettai, Killai, Kollidam, and Kodiyambalaiyam—are where sea sand is gathered. The Cuddalore District's East Coastal region, which stretches from Vellar Easturine to Coleroon Estuarine, selected these four locations. Figure 1 displays a map of the area where sea sand is harvested. Although the four sea sand samples have distinct properties, Parangipettai sea sand has numerous advantages over river sand. Consequently, sea sand from Parangipettai was used throughout the duration of the experiment.

2.2 Features of the Sea Sand

Coastal soils have few physical characteristics. These features are typically examined in conjunction with other aspects of the soil. Coastal soils can have a broad range of textures, from loose sandy deposits to heavy soils. Along the profiles of coastal soils, size fraction distribution is highly irregular and erratic. Coastal soils typically include loose, structure-free sand layers, though occasionally they can be partially compacted or even solid. Sandy horizons are distinguished by high permeability to both air and water. As a result, sandy soils have relatively high aeration and are less susceptible to water logging than clayey soils. Sandy soils have a bulk density that is marginally greater than 1 g/cm3. There isn't more than 10% to 20% water content.

Fig.1.The Map showing the sea sand samples collected area.

2.3 River sand

Typically, concrete uses river sand as the fine aggregate. River sand was used in this study to partially replace the concrete. According to Indian Standard IS 10500: 1991, the river sand used in concrete is clear, free of clay, and has sharp granules with chemical properties that are within the permitted range. Particles in the river sand range in size from 4.75 to 75 microns.

2.4 River sand's characteristics

The sand is orange, yellow, and brown in tint. River sand has granules that are smaller than 4.75 mm.99.5% of SiO_2 is in a pure state. The impurities that are present are Fe_2O_3 and Al_2O_3 (0.5%). The melting point is 1722 °C, however, it drops to 1290 °C using a flux agent. River sand comes in different particle sizes and has a consistent size. It has the ability to lessen cracks caused by shrinking.

2.5 Sea Sand and River Sand Comparison

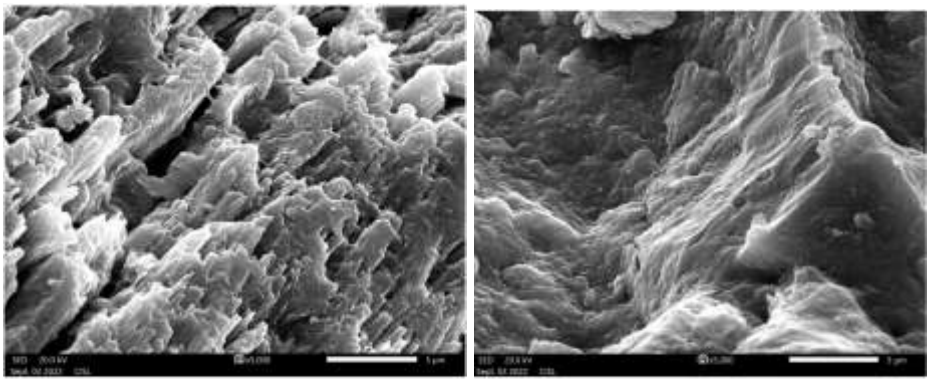
Sea sand has a higher SBC (safe bearing capacity) than river sand. This is because bigger stone fragments constantly break down as they get closer to the sea and separate into the smallest possible pieces. When water continuously rolls in between water levels in rivers and the shoreline, it is either pushed by the seashore or by rivers, bringing sea sand with it (which can be imagined as an infinite time process). The leftover fragments of broken sand at the beach will be much more powerful than any other sand on Earth.

Sand Test: Various tests were performed on sea sand to ascertain its characteristics.

Specific Gravity Test: The weight of a particular volume of solids divided by the weight of an equal volume of water at 4C is known as the specific gravity of solids.

Weight of empty bottle (kg) = $W2 – W1 / (W4 – W1) – (W3 – W2)$ is the formula for specific gravity. W2 = Weight of dirt (300g) and bottle (kg) after it has been dried in an oven and cooled W3 = Soil, water, and bottle weight (kg) W4 = bottle and water weight (kg)

This study looks at the chemical properties of several components used to make concrete, including river and seashore sand. The study's materials are shown in Figure 2.



a)Sea sand b) River sand

Figure 2: Image of sea sand and river sand

2.6 Properties of fine aggregate

From six different places of Cuddalore the fine aggregate has been gathered. The surface texture, water absorption, fineness modulus, specific gravity, Bulk density, Sea Shell content, and Clay Lumps were determined during the experiment. Table 1 categorises and summarises the characteristics of the fine aggregate employed in this investigation.

Table 1: Sea sand properties

Properties of Sand	River Sand	Pebbles Sand	Kodiyampalaiyam	Killai	Parangipettai	Kollidam	Acceptance Limit	IS Code
Surface	Round	Slightly	Rounded	Roun	Slightly	Roun	Angular	IS:238

Texure	ed	Angular		ded	Angular	ded		6 (Part II)- 1963 IS: 383 - 1970 IS: 2116-1980 ASTM : C40/C40M-11 AASHTO NO: T-21 BS: 812-118:1988
Water Absorption	1.00%	0.80%	0.52%	0.60 %	0.75%	0.62 %	Below 3% by Mass	
Fineness Modulus	2.78	2.92	2.75	2.56	2.85	2.32	2.22 to 3.20	
Specific Gravity	2.67	2.74	2.97	2.82	2.64	3.01	2.6 to 2.9	
Bulk Density	1527	1458	1562	1763	1533	1624	1520 to 1680 Kg/m3	
Sea Shell Content	0.02%	***	0.07%	0.04 %	0.03%	0.05 %	0.10%	
Clay Lumps	0.05%	***	***	0.02 %	***	***	0.10%	
PH Value	8.23	8.35	8.5	8.24	8.26	8.79	Above 7	
Sulphate Content	0.01%	0.03%	***	0.02 %	***	***	0.10%	
Chloride Content	0.02%	0.02%	0.01%	0.03 %	0.01%	0.04 %	0.10%	
Grading Zones	II	III	II	I	II	I	II, III	

2.7 Chemical properties

Collected sand is stored in a safe place and 50 gm of sand is taken from each sample. It was put into the conical flask and 200 ml distilled water is added and kept for one day. After that, it was placed in a rotary shaker for one hour. Later it was filtered by the filter paper. At this stage, each sample was tested for pH value, chloride, sulphide, hardness, TDS, Calcium, sodium and Bicarbonate.

2.8 Determination of ph value:

pH value for each sample is respectively prepared in the buffer tablets and the temperature of this buffer solution is 30 degree celsius. To calculate the pH value this solution was placed in the elctrode stand. Figure 3 demonstrates the pH value.

Figure 3 : pH value

2.9 Determination of hardness

In this stage 50 ml of smaple taken from the conical flask and add 2 ml of buffer solution with 3 dropsof Erichrome Black 'T' indicator. Hardness test image given in figure 4.

Figure 4 : Hardness test

2.10 Determination of Chloride content

3 dops of K_2CrO_4 (Potassium Chromate) was added to the 50 ml sample in the conical flask. Thus the Cholirde content was determined. Figure 5 delivered the image of chloride test.

Figure 5 : Chloride test

2.11 Determination of Sulphide Content

For this test 10 ml of Barium chloride and 10 ml of sodium chloride were taken and add to 50 ml of sample. Thus the Sulphide content calculated. Figure 6 shows the sulphide test.

Figure 6 : Sulphide test

2.12 Sieve analysis

The sieve number, as per Indian Standard Code IS: 460-1962 (Revised), is the mesh width, given in microns for small sizes and in millimetres for large sizes. The I.S. sieve set for fine sieve analysis has the following sieve sizes: 2 mm, 1 mm, 600µ, 425µ, 212µ, 150µ, and 75µ. One kilogram of dry soil, or sea sand, is used for the dry sieve analysis. The sieve analyses of the aggregated river and sea sand are displayed in Tables 2 and 3.

Table 2: Seive analysis of river sand

IS Sieve No	Weigth of FA Retained	Percentage of Retained	Cumulative Percentage of retained	Percentage of Passing	Permissble value from IS 383
4.75 mm	0	0	0	100	I II III IV
2.36 mm	3	3	0.3	99.7	II III IV
1.18 mm	146	149	14.9	85.1	II III
600 Micron	400	549	54.9	45.1	II
300 Micron	391	940	94	6	I
150 Micron	47	987	98.7	1.3	I II III IV
75 Micron	10	997	99.7	0.3	***
Pan	3	1000	100	0	***
Fineness Modulus			**4.625**	**Zone**	**II**

The top sieve in the stack has a lid on it, and a receiver is stored at the bottom. The mechanical shaker is used to shake. Weighing is done to the closest 0.1 g for each sieve's retained soil volume. A seive analysis test was performed on both sea and river sand.

Table 3 : Sieve analysis of sea sand

IS Sieve No	Weigth of FA Retained	Percentage of Retained	Cumulative Percentage of retained	Percentage of Passing	Permissble value from IS 383
4.75 mm	0	0	0	100	I II III IV
2.36 mm	3	3	0.3	99.7	II III IV
1.18 mm	146	149	14.9	85.1	II III
600 Micron	400	549	54.9	45.1	II
300 Micron	391	940	94	6	I
150 Micron	47	987	98.7	1.3	I II III IV
75 Micron	10	997	99.7	0.3	***
Pan	3	1000	100	0	***
Fineness Modulus			**4.625**	**Zone**	**II**

2.12 Scanning Electron Microscopy (SEM) Analysis

For visually inspecting particles that are too small to be seen with an optical microscope, SEM with EDS is a useful instrument. An electron beam is directed towards the specimen's surface in order for the SEM to function. Electrons will either be absorbed or scattered when they come into contact with a solid object.

3. RESULT AND DISCUSSION

3.1 Chemical composition of river sand

A study of chemical properties is shown in Table 4. Silica sand from quartz is usually the main component of river sand since it is comprised of the same material as the adjacent rock from which it eroded. Our river sand is sub-angular in shape, unlike that from other sources, which could be spherical. The pH value of an aqueous solution is used to determine how basic or acidic it is. A pH of less than 7 is considered acidic, whereas a pH of greater than 7 is considered basic or alkaline. The pH of pure water is extremely near to 7. Typically, a PH metre that displays the value after the electrode has been dipped in the solution whose PH has to be evaluated is used in conjunction with a buffer solution to make this determination. River sand is utilised as the fine aggregate in concrete because of its high alumina and silica concentration. The further extraction and use of river sand results in its depletion and a departure from sustainability. For a river, a range of 45–155 mg/L is regarded as typical. 2. For groundwater, a range of 35–125 mg/L is regarded as typical. It creates a great texture for concrete by retaining moisture in the spaces between the particles. Oversized Items: 1-6 percent Particle size: up to 3% at 75 microns form: Better form and a smooth texture.

Table 4: Analysis of chemical properties

S. No	DESCRIPTION	VALUE					INDIAN STANDARD
		RIVER Sand	PARANGIPETTAI	KILLAI	KODIYAMPALAIYAM	KOLLI DAM	
1	PH Value	8.23	8.26	8.24	8.5	8.79	Above 7
2	Chloride	96	85	104	92	87	Below 1000Mg/l
3	Sulphate	14	6	28	32.56	12	Below 400Mg/l
4	Hardness	100	124	75.23	114.8	118.64	Maximum 600Mg/l
5	TDS	143	368	342	302	125	Below 1000Mg/l
6	Calcium	309.5	412	435	426.7	454	Maximum 200Mg/l
7	Sodium	84.8	162.45	124.1	136.74	128.65	Maximum 200Mg/l
8	Bi-Carbonate	54	62	71	84	68.12	Below 600Mg/l

3.2 IS Sieve analysis of River and sea sand

Locally sourced aggregates were employed. The coarse particles were 6 mm to 20 mm in size. Both the coarse and fine aggregates are stored in a saturated–surface dry state (SSD) before being used in the concrete. In compliance with IS 2386 (parts 1, 2, and 3) - 1963, tests were conducted on both fine and coarse aggregates. It is noted that zone II is followed by the fine aggregate utilised in this project. Tables 5,6 and 7 display the sieve analysis results for river sand, 20 mm and down size coarse aggregates, and 12 mm and down size coarse aggregates. Figure 7,8 and 9 display the properties of river sand, 20 mm and down size coarse aggregates, and 12 mm and down size coarse aggregates, respectively.

Table 5: Sieve analysis

	IS Sieve No	Percentage of Passing		
		River Sand	Sea Sand	
4.75 mm	**0**	0	0	100
2.36 mm	**0.075**	0.5	0.4	99.7
1.18 mm	**0.15**	1.3	38.4	85.1

600 Micron	**0.3**	15.4	75.6	45.1
300 Micron	**0.6**	45.8	92.15	6
150 Micron	**1.18**	74.15	98.21	1.3
75 Micron	**2.36**	86.52	100	0.3
Pan	**4.75**	93.4		0

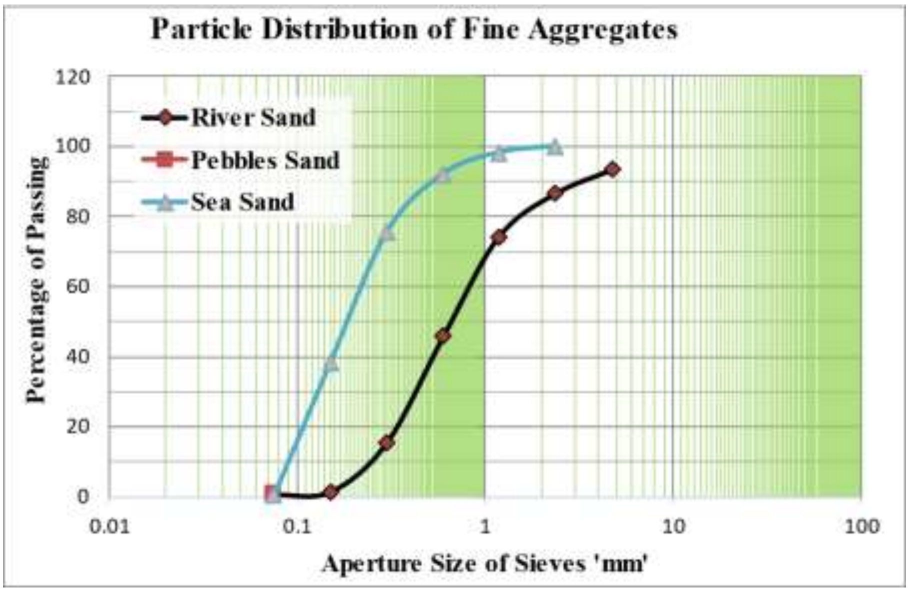


Figure 7: Particle distribution of river sand

In this test, a series of IS sieve sizes are applied to the sand sample, ranging from bigger to smaller ones at the bottom. The weight of the sand held on each IS Sieve is then determined once a suitable-sized sand particle is retained on a sieve. The proportion of sand retained on each IS Sieve is then computed to represent the particle size distribution in the sand sample. The sieve analysis procedure provides essential information about the grading and suitability of sand for various application, it aids in understanding important properties such as porosity, compact ability and permeability, which is crucial in field like civil engineering and construction. The outcome of the sieve analysis provides a visual representation of the particle size distribution of the sand sample by the computation of the cumulative percentage of passing particles and the display of a grain size distribution curve.

Table 6: Sieve Analysis

	IS Sieve No	Percentage of Passing	
4.75 mm	**0**	0	100
2.36 mm	**0.075**	0.4	99.7
1.18 mm	**0.15**	38.4	85.1

600 Micron	**0.3**	75.6	45.1
300 Micron	**0.6**	92.15	6
150 Micron	**1.18**	98.21	1.3
75 Micron	**2.36**	100	0.3
Pan	**4.75**		0

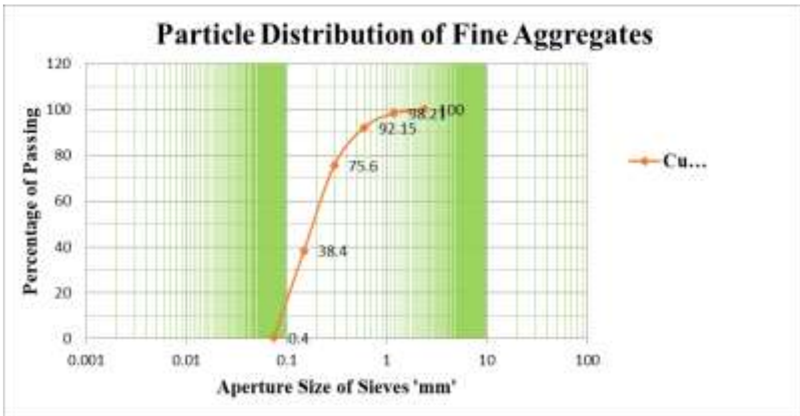


Figure 8: Particle distribution of sea sand

When the aforementioned experiments are repeated using the purified sea sand and river sand that were taken out of the experimental setup, the results for specific gravity and sieve analysis will be equal. Because of this, the properties of both regular and purified sea sand will not change; during the purification process, the salt content will decrease but the water and salt content will stay at the top. Through the outlet, this salt-filled water is eliminated. The cylinder and the sand are separated. After multiple iterations of the procedure, around 75–80% of the salt is removed, yielding fresh sand. The sand is damp and gets dried for hours under the sun.

Table 7 : Seive analysis for combined sand

IS Sieve No	Percentage of Passing	
	River Sand	Sea Sand
0	0	0
0.075	0.5	0.4
0.15	1.3	38.4
0.3	15.4	75.6
0.6	45.8	92.15
1.18	74.15	98.21

2.36	86.52	100
4.75	93.4	

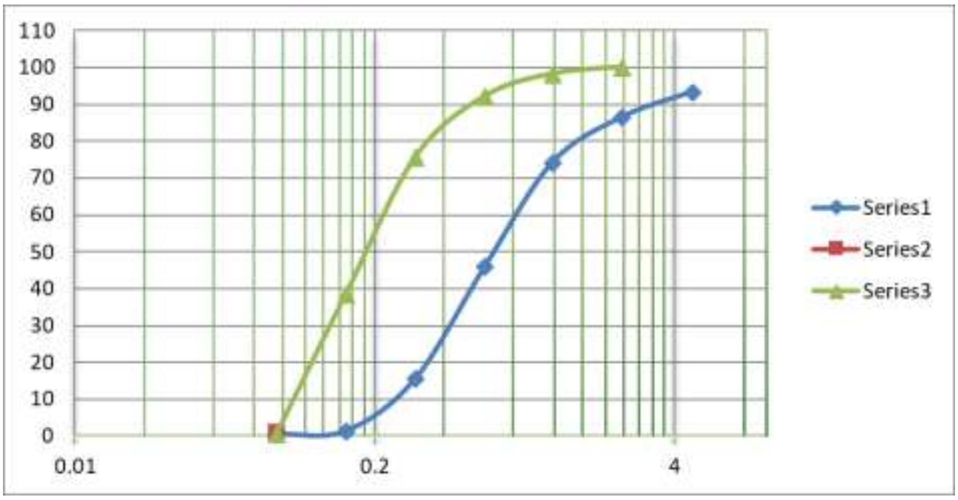


Figure 9: Particle distribution of combined sand

3.3 MICRO STRUCTURE OF SEA SAND

Indicates that the particles are spherical in shape which influence in the workability of concrete. According to the EDS analysis the element is identified as Light elements where atoms return to fundamental state mainly by Auger emission. In addition, the low energy makes it easily absorbed.

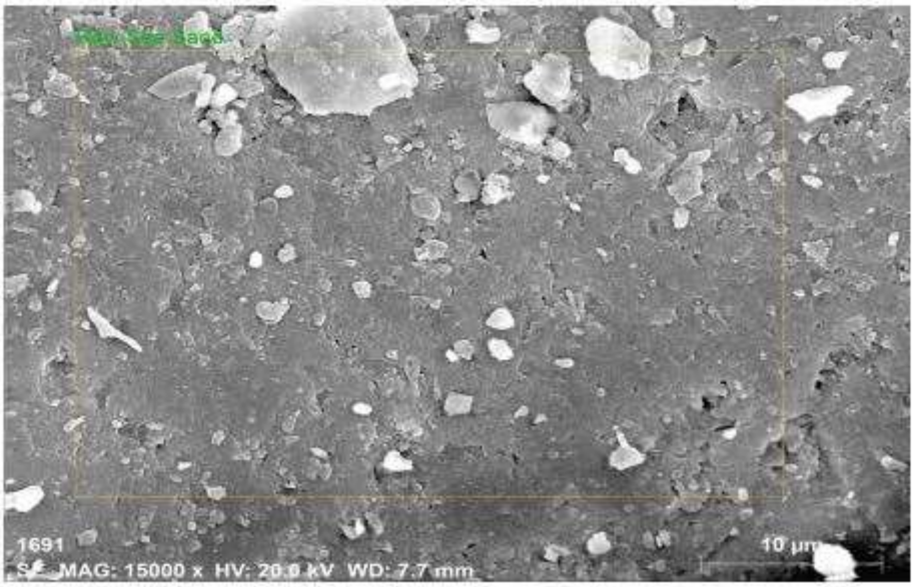


Figure 10 SEM Image of Sea Sand

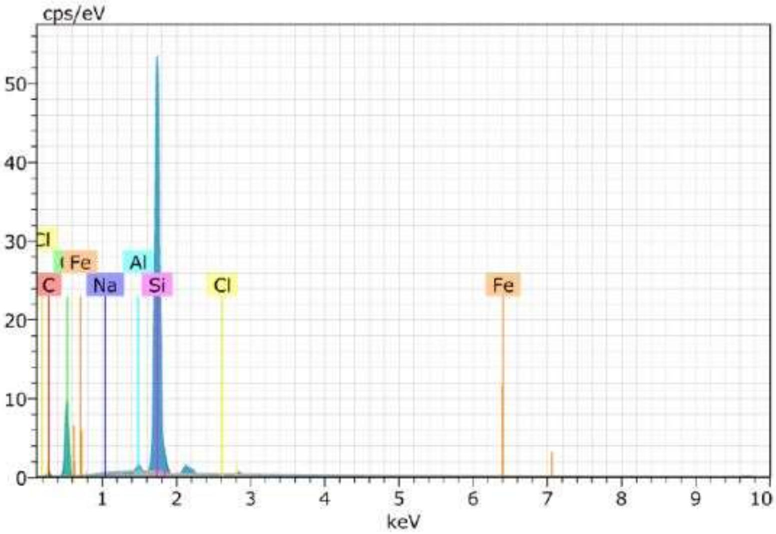


Figure 11: EDS Analysis of Sea Sand

From Figure 11 it is clearly understood that silica, oxides and Chlorine are the elements present in the raw sea sand. Silica is higher in quantity here which reacts with cement creates Calcium Silicate Hydrates (CS-H) and increases the strength of the concrete but the level of chlorine whichdisturbs the durability of concrete. Hence the raw Sea sand was treated with water and hot water wash method to remove the chlorine.

4. Conclusion

The goal of the endeavour is to use sea sand in place of river sand in order to raise the high strength of concrete from the locations of Parangipettai, Killai, Kollidam, and Kodiyambalaiyam. Thus, this study's main objectives were to compare the results of several tests conducted on water to determine hardness and to look at how concrete strength changed before and after the salt component of the sea sand was eliminated. Sea sand is utilised in the building sector to lessen the quantity of salt in the sand. After the sea sand has been purified, a number of experiments are conducted on it using the experimental apparatus, and after the device has been rinsed, water is removed. A partial blend of river sand and cleaned sea sand reaches the necessary strength after 28 days. In the future, sea sand will replace river sand to satisfy the demand for river sand in construction. The purified sea sand is more durable than river and unpurified sea sand. It has been shown, therefore, that corrosion is under control. The study concluded that sea sand must have its salt removed in order for construction projects to be more feasible and long-lasting.

Abbreviation

M-sand - Manufacture Sand

ICCP - Impressed Current Cathodic Protection

DVS - Dynamic Vapour Sorption

Rh - Relative Humidity

SWSSC - Saltwater Sea Sand Concrete

SWSSC- UHPc - Seawater and sea sand based ultra-high performance concrete

SCM - Supplemental cementitious materials

DECLARATION

Ethics approval and consent to participate

Not applicable

Consent for Publication

Not applicable

Availability of data and materials

I am not ready to share my data, because it is highly confidential .

Competing interests

The authors declare no conflicts of interest.

Funding

This research study is sponsored by the PSNA College of Engg &Tech, Coimbatore. Thank you to this college for supporting this article!

Authors' Contribution

K. Bhagyalakshmi supports to develop literature, and methodology part in this manuscript. 5 Hypothesis testing and the influence of socio-demographic factors using ANOVA was a major contribution by **S. Jayaraman**.

Acknowledgment

I offer up our fervent prayers to the omnipotent God. I want to express my sincere gratitude to my co-workers for supporting me through all of our challenges and victories to get this task done. I want to express my gratitude for our family's love and support, as well as for their encouragement. Finally, I would like to extend our sincere gratitude to everyone who has assisted us in writing this post.

REFERENCES

1. Karthikeyan, M., and V. Nagarajan. "Chloride analysis of sea sand for making concrete." *National Academy Science Letters* 40 (2017): 29-31.
2. A.B.M.A. Kaish et al., "Effects of different industrial waste materials as partial replacement of fine aggregate on strength and microstructure properties of concrete" https://www.sciencedirect.com/journal/journal-of-building-engineering Volume 35, March 2021, 102092.
3. S. Pranavan and G. Srinivasan, "Investigation on behaviour of M-sand and sea sand based concrete" Materials Today: Proceedings Volume 45, Part 7, 2021, Pages 7079-7085. https://doi.org/10.1016/j.matpr.2021.01.930 .

4. Kartheek Thunga, T. Venkat Das., “An experimental investigation on concrete with replacement of treated sea sand as fine aggregate” Accepted 17 January 2020; Materials Today: Proceedings https://doi.org/10.1016/j.matpr.2020.01.356 .
5. Wei Liu et al., “Modelling analysis of chloride redistribution in sea-sand concrete exposed to atmospheric environment” Accepted 4 December 2020; Construction and Building Materials. https://doi.org/10.1016/j.conbuildmat.2020.121962 .
6. Menghuan Guo et al., “Characterization of the mechanical properties of eco-friendly concrete made with untreated sea sand and seawater based on statistical analysis” Construction and Building Materials Volume 234, 20 February 2020, 117339. https://doi.org/10.1016/j.conbuildmat.2019.117339 .
7. Mei-ni Su et al., “A solution for sea-sand reinforced concrete beams” Construction and Building Materials Volume 204, 20 April 2019, Pages 586-596. https://doi.org/10.1016/j.conbuildmat.2019.01.146 .
8. Adel Younis et al., “Fresh and hardened properties of seawater-mixed concrete” Construction and Building Materials Volume 190, 30 November 2018, Pages 276-286. https://doi.org/10.1016/j.conbuildmat.2018.09.126 .
9. Jianzhuang Xiao et al., “Use of sea-sand and seawater in concrete construction: Current status and future opportunities” Construction and Building Materials, Volume 155, 30 November 2017, Pages 1101-1111. https://doi.org/10.1016/j.conbuildmat.2017.08.130 .
10. Vafaei, D., Ma, X., Hassanli, R., Duan, J. and Zhuge, Y., 2022. Microstructural behaviour and shrinkage properties of high-strength fiber-reinforced seawater sea-sand concrete. *Construction and Building Materials*, *320*, p.126222.
11. Zhang, Kaijian, Qingtian Zhang, and Jianzhuang Xiao. "Durability of FRP bars and FRP bar reinforced seawater sea sand concrete structures in marine environments." *Construction and Building Materials* 350 (2022): 128898.
12. Xie, Jianhe, et al. "Effects of immersion in water, alkaline solution, and seawater on the shear performance of basalt FRP bars in seawater–sea sand concrete." *Journal of Composites for Construction* 26.2 (2022): 04021071.
13. Saleh, Shameer, et al. "The mechanical, transport and chloride binding characteristics of ultra-high-performance concrete utilising seawater, sea sand and SCMs." *Construction and Building Materials* 372 (2023): 130815.
14. Feng, Wanhui, et al. "Mechanical behavior and constitutive model of sustainable concrete: Seawater and sea-sand recycled aggregate concrete." *Construction and Building Materials* 364 (2023): 130010.