

A STUDY ON NON DESTRUCTIVE TESTS AND MECHANICAL PROPERTIES OF CONCRETE USING MARINE SAND

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Abstract

Developing countries like India are investing heavily in infrastructure, highway projects, metro projects, and smart cities as part of their plans to boost their economy. This growing building sector requires a substitute for river sand. In an effort to reduce the exploitation of natural aggregates, this study promotes the use of washed marine sand (MS) as a fine aggregate to partially or completely replace M-Sand will address the need for alternative building materials. This approach contributes to river conservation efforts and helps mitigate erosion and flooding. The purpose of this experimental investigation is to analyze the mechanical characteristics of concrete and conduct Non-Destructive Tests (NDT) on concrete that incorporates washed marine sand as a partial replacement for M-Sand (Ashwini & Kiran, 2018). The novelty of the study includes combination of M-Sand and MS to substitute the scarce fine aggregate namely river sand, will cater to the societal need of finding sustainable construction materials and establishing correlations between NDT results and mechanical strength for marine sand concrete. This research evaluates concrete strength characteristics in line with the guidelines of IS 516-1959, focusing on split tensile strength, crushing strength and bending strength. Six samples of concrete specimens are tested using washed marine sand for replacing M-Sand at varying levels of 20% to 100%, labeled as M100, MS20, MS40, MS60, MS80, and MS100. From this experimental investigation, 60% of partial replacement of marine sand meets the required strength properties. Also, from this study a comparison is made between theoretical predictions and experimental findings.

Keywords: Compressive Strength; Concrete; Marine Sand; NDT Test; Split Tensile Strength

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Introduction

Conventional concrete is made up of cement; water, fine and coarse aggregates, and is mostly utilized in the building industry. The workability, strength, and longevity of concrete are all significantly influenced by the fine aggregate component. Because of its advantageous physical and chemical characteristics, river sand has historically been the main option for fine aggregates. The depletion of natural resources and growing environmental problems Research on substitute materials, such as marine sand, has been prompted by river sand resources. This study shows mechanical properties of concrete using marine sand as a fine aggregate. This study intends to close this gap by establishing relationships between rebound hammer values, ultrasonic pulse velocity, and compressive strength for marine sand concrete, thereby contributing to a reliable in-situ assessment method. While prior research has investigated the viability of using marine sand as a partial or complete replacement for river sand, little research has systematically evaluated the correlation between non-destructive testing (NDT) parameters and mechanical properties of such concrete. Liu *et al.* (2021) focused on the effects of carbonation on chloride in concrete made with dredged marine sand (DMS). Their investigation analyzed the physical and chemical behavior of DMS at the microstructural level, highlighting concrete carbonation and the behavior of DMS chloride within the material. The findings revealed that chloride ions are physically adsorbed and released as free ions during the breakdown of C-S-H gel. Additionally, an increased capillary pore ratio was found to reduce the diffusion rate of CO₂ (Dong *et al.*, 2018). With its superior resistance to carbonation, DMS concrete effectively mitigates steel reinforcement corrosion. However, free chloride ions in DMS also contributed to increased carbonation in the material (Dang *et al.*, 2021).

Dhondy *et al.* (2020) observed that the mineral composition and particle size distribution varied across the analyzed sand samples. Sea sand exhibited a smoother and rounder texture, along with a narrower particle size range compared to standard sand. Variations were also identified among sea sand samples collected from nine different locations along coastline, indicating that mineralogy, particle size distribution, and surface roughness can differ based on the source (Dhondy *et al.*, 2019). These factors affect the characteristics of both fresh and hardened concrete. Research indicates that marine sand with characteristics comparable to conventional sand does not compromise concrete performance (Chen *et al.*,

2022). Furthermore, compared to conventional concrete, this investigation showed that the mechanical characteristics of sea sand-seawater concrete remained unaffected, even the marine sand exhibited a smaller particle size distribution and evenly dispersed chlorides (Feng *et al.*, 2021). Indhumathi *et al.* (2023) observed that among the DMS specimens reflecting densely packed particles, the largest ultrasonic pulse velocity is achieved in the case of D100. In the D40 to D60 specimens, the decreased pulse velocity indicates the presence of voids between two distinct fine aggregates. According to experimental research, when mix design parameters are optimized, marine sand concrete has compressive strengths that are similar to those of ordinary concrete. For example, Sun *et al.* (2025) found that fiber-reinforced marine sand concrete had better mechanical qualities and durability to harsh environments. Additionally, Kandou *et al.* (2025) showed that self-compacting concrete with seawater and sea sand can attain acceptable workability and strength properties.

Seabed's and coastal regions are the natural sources of marine sand, which is distinguished by its smooth texture and fine particle size. Nevertheless, it frequently contains contaminants including organic waste, shell fragments, and chloride ions, which can affect how well concrete works. To lessen these negative consequences, researchers have concentrated on cleaning and treating coastal sand. According to Ahmed *et al.* (2020), the workability and early compressive strength of concrete are affected when freshwater and river sand are substituted with seawater and marine sand. However, saltwater sea sand concrete (SWSSC) can meet the necessary strength and workability requirements for real-world applications with an appropriate mix design. However, the study found that saltwater sea sand concrete (SWSSC) can meet the practical workability and strength requirements for structural usage with a well optimized mix design. In marine and coastal environments, the enhanced surface texture of FRP bars can improve their durability. Comparative tests indicated that GFRP bars exhibit greater durability than BFRP bars under saline conditions (Bayesteh *et al.*, 2020). Nevertheless, prolonged exposure and elevated temperatures may accelerate the deterioration of FRP bars in SWSSC, negatively affecting flexural and shear performance (Balaji & Vetturayasudharsanan, 2020). Additionally, FRP bars are more susceptible to degradation in conventional SWSSC pore solutions compared to those in high-performance SWSSC pore solutions.

Materials and Methods

Manufactured Sand

Figure 1 shows M-Sand, and Figure 2 illustrates MS, which are blended in varying proportions to achieve the optimal mix. M-Sand is a type of crushed aggregate derived from hard granite rock. It is processed to maintain a shape of cubical with smooth, rounded edges, ensuring consistent cleaning and grading. Additionally, M-Sand adheres to the Zone II classification outlined in IS 383-2016 (Bureau of Indian Standards, 2016). Figure 3 shows XRD Analysis of M-Sand.



Figure 1. M – Sand

Marine Sand (MS)

Washed marine sand (MS) was obtained from Tamil Nadu's Tiruchendur coastline and used as sand. An XRF test was used to investigate the chemical components of MS in order to determine the chloride level. The physical characteristics of coastal sand are also examined in Table 1 and Table 2 displays the findings of the chemical composition study. Chlorine is the substance that causes steel to corrode (Al-Fakih *et al.*, 2021). Therefore, it must be within the allowed limits (less than 0.05%) in order to be utilized in concrete. Thus, MS is cleansed with fresh water and dried to reduce the Cl level to 0.02%. Figure 4 displays the XRD Analysis of Marine Sand.



Figure 2. Marine Sand

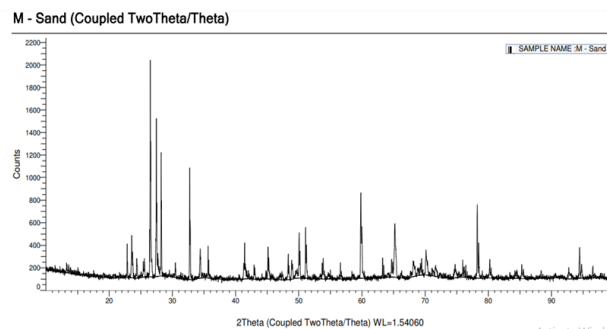


Figure 3. XRD Analysis of M-Sand

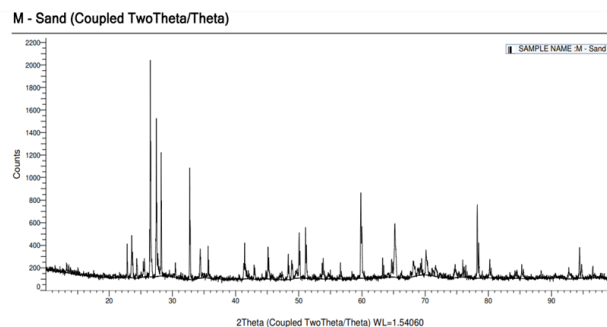


Figure 4. XRD Analysis of Marine Sand

Cement and Coarse Aggregate (CA)

Tables 1 and 3 provide details on the physical properties of the cement as per IS 12269-2013 (Bureau of Indian Standards, 2013) and aggregates used in the various mixes.

Mix Design

The quantities for the M25 grade mix design are determined in accordance with IS 10262:2009 (Bureau of Indian Standards, 2009) and IS 456:2000 (Bureau of Indian Standards, 2000). The calculated amounts of the ingredients are displayed in Table 4.

Test Methods

According to IS 516-1959 (Bureau of Indian Standards, 1959b) and IS 456:2000 (Bureau of Indian Standards, 2000), the fresh, mechanical properties and NDT Tests on concrete are examined. The study includes testing the mechanical characteristics of concrete of flexural strength, compressive strength and split tensile strength. The specific mix proportions for the concrete samples are outlined in Table 5.

Non-Destructive Test (NDT)

The strength values derived from the destructive tests were verified using non-destructive testing techniques like the rebound hammer method and the ultrasonic pulse velocity test.

Ultrasonic Pulse Velocity (UPV) Test

In order to evaluate the quality of concrete, Helal *et al.* (2015) observed that the ultrasonic pulse velocity technique was used in accordance with IS 13311 (Part 1)-1992 (Bureau of Indian Standards, 1992). Proceq equipment with transducer 54 kHz including calibration rod, coupling agent as grease used for UPV testing. Measurement conditions for concrete surface has been clean, smooth, and free from loose particles before conducting the test. A suitable coupling medium is applied between the transducer face and concrete surface to eliminate air gaps. It was measured how long it took the ultrasonic pulse to pass through the concrete samples. Figure 5 shows how the test is configured. Two parts make up the testing apparatus: a pulse generator that sends out waves and a pulse receiver

Table 1. Properties of aggregates

Physical property	M-Sand	Marine sand (MS)	Coarse aggregate
Fineness modulus	3.478	2.256	7.45
Grading	Zone II	Zone IV	Zone II
Specific gravity	2.65	2.65	2.7
Water absorbing capacity	2.556%	1.943%	0.65%

Table 2. Chemical analysis of marine sand (MS)

Property	Si	K	Ca	Fe	O	Cl
Before washed	30.88%	8.88%	15.94%	2.18%	43.89%	0.03%
Washed and dried	43.74%	-	5.87%	-	51.63%	0.021%

Table 3. Physical analysis of Cement

Physical Property	Specific Gravity (no unit)	Soundness	Standard Consistency in %	IST	FST
OPC 53 Grade cement	3.15	4.6mm	32%	60 minutes	370 minutes

Table 4. Mix Ingredients in kg/m³

Mix ID	Cement	Water	M-Sand	MS	CA
M100	421.55	197.09	709.67	-	1230.1

Table 5. Mix Identity for Concrete (Each mix 3 specimens for each test)

S.No.	Mix ID	M-Sand (%)	MS (%)
1	M100	100	0
2	MS20	80	20
3	MS40	60	40
4	MS60	40	60
5	MS80	20	80
6	MS100	0	100

M – M-Sand, MS –Washed Marine Sand

that picks them up. The waves are produced and received by the piezoelectric crystals that are incorporated into the apparatus. The concrete quality is according to the measured pulse velocity. Equation (1) is used to compute the velocity.

$$\text{Pulse velocity, } V = L/T \quad (1)$$

Where, L = Path length and T = Travel time

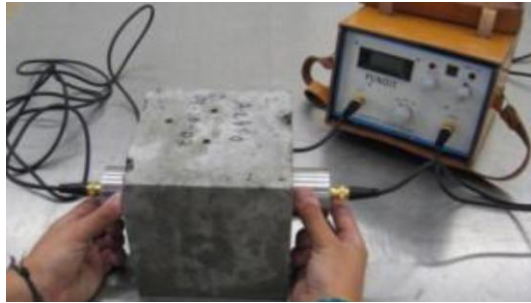


Figure 5. Ultrasonic Pulse Velocity Test

Rebound Hammer Test

The rebound hammer test was conducted in compliance with IS 13311 (Part 2):1992 (Bureau of Indian Standards, 1992(b)). At least ten impact measurements were obtained for each specimen at various points on the test surface. To reduce local variability, the test spots were chosen to be evenly spaced around the specimen's surface, avoiding corners, edges, and obviously flawed areas. The concrete surface was cleaned and levelled with a grinding stone to get rid of loose particles and laitance before testing. To guarantee uniformity in rebound readings, all specimens were tested on dry surfaces. A spring-controlled mass that travels along a plunger inside a tubular casing makes up the rebound hammer. The compressive strength of the concrete can be evaluated by comparing the rebound

index with the compressive strength. This method is useful for identifying areas of a structure that may pose issues or meet the required standards. A scale was used to measure the rebound distance after the hammer (Figure 6) was hit against the concrete surface during the test. Each rebound hammer value represents the average of multiple readings taken at different points on three specimens, and the results are reported as mean $\pm$ standard deviation.

Mechanical Properties of Concrete

Compressive Strength

Concrete cubes of $150 \times 150 \times 150\text{mm}$ (Figure 7) and M25 grade, in accordance with IS 516-1959 (Bureau of Indian Standards, 1959b), was prepared to determine the crushing strength. A total of 6 specimens (Figure 7) were used and tested for every mix. The specimens were tested for compressive strength, as shown in Figure 8, after curing for 7 and 28 days. Compressive strength was calculated using the formula provided in Equation 2:

$$f_c = P/A \quad (2)$$



Figure 7. Casting of cube specimens



Figure 6. Rebound hammer Test



Figure 8. Testing of compressive strength for concrete

Split Tensile Strength

Cylinder specimens with dimensions of 150 mm × 300 mm were cast according to ASTM C496 (ASTM International, 2017) specifications to calculate the split tensile strength as shown in Figure 9. The load was applied along the length of the cylinders until failure occurred. The cylindrical split tensile strength was calculated using Equation 3. The load was applied gradually, without shock, increasing steadily as per IS 5816-1999 (Bureau of Indian Standards, 1999).

$$f_t = 2P/\pi dL \quad (3)$$



Figure 9. Testing of split tensile strength



Figure 10. Testing of Flexural Strength

Flexural Strength

Prism specimens of 100 × 100 × 500mm were cast to evaluate the flexural strength of concrete on a smaller scale. The concrete samples were tested using UTM equipment with a maximum capacity of 400 kN as shown in Figure 10. The testing procedure adhered to the guidelines outlined in IS 516-1959 (Bureau of Indian Standards, 1959b). A three-point loading method was applied along the length of the prisms, where the applied load was gradually improved at a controlled rate until failure occurred (Leema Margret *et al.*, 2023). The bending strength was then calculated based on the formula

provided in Equation (4). This method is commonly used to assess the ability of concrete to endure bending forces and provides an important measure of its overall structural performance.

$$\text{Flexural Strength } f_b = PL/bd^2 \quad (4)$$

where, L = Supported length (mm)
 P = Maximum load (N)

Results and Discussion

Non Destructive Test

This section discusses the results obtained from both the NDT tests using rebound hammer and the ultrasonic pulse velocity apparatus.

Rebound Hammer Test

Table 6 presents the values of hardness found for various mixes of concrete using rebound hammer test results with error bars.

Table 6. Rebound hammer test results

S. No.	Mix ID	Mean Hardness (N/mm ²)
1.	M100	28.29 ± 0.85
2.	MS20	28.08 ± 0.78
3.	MS40	27.26 ± 0.72
4.	MS60	26.21 ± 0.69
5.	MS80	25.22 ± 0.81
6.	MS100	23.86 ± 0.94

To account for measurement variability, the rebound hammer test results are displayed as mean values plus standard deviation. Surface hardness measures are consistent across all combinations, as seen by the comparatively low standard deviation. From the rebound hammer test results as shown in Figure 11, among the MS specimens, M100 exhibits the highest hardness value. When comparing the control mix specimens, MS20 shows the maximum value. Overall, M100 performs similarly to the MS20, MS40, and MS60 specimens. MS20 provides a strength of 28.08 N/mm², with a minimal variation of 0.21 N/mm² compared to M100, indicating strong performance. Additionally, equivalent rebound values were displayed by concrete mixes MS40 and MS60, indicating satisfactory surface quality and homogeneity. However, from MS60 to MS100, the strength decreases due to inadequate cohesion between the two distinct fine aggregates and changes in particle packing and decreased inter-particle bonding at greater marine sand replacement may be the cause of this decline, which can affect surface hardness readings. The addition of error bars to Figure 11

improves the data's dependability and validates the statistical consistency of the hardness decrease shown with increased sea sand concentration. By showing that NDT-based strength estimate models may be fairly extended to marine sand concrete, the study's findings offer a novel contribution. This fills a crucial gap in real-world situations where destructive testing is not practical.

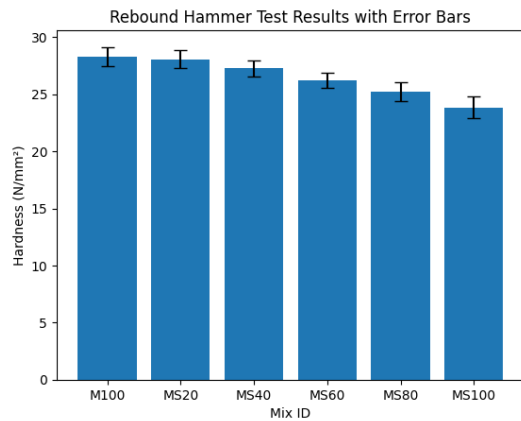


Figure 11. Rebound hammer test results with error bar

Ultrasonic Pulse Velocity Test (UPV)

In Table 7, the Non-Destructive testing of UPV test was conducted, and the results obtained are presented.

A dense and well-compacted interior structure was indicated by the control mix (M100), which had the greatest pulse velocity value of 4.18 km/s. According to IS 13311 (Part 1):1992 (Bureau of Indian Standards, 1992(a)), MS20, one of the marine sand-based mixes, showed a pulse velocity of 4.00 km/s, which is similar to the control mix and corresponds to high-quality concrete.

The results for all mixes are displayed in Figure 12. Among the MS specimens, M100 exhibits the highest ultrasonic pulse velocity, indicating well-compacted particles. The average pulse velocity of the specimens, from MS20 to MS60, reflects good homogeneity, as per IS 13311 (Part 1):1992 (Bureau of Indian Standards, 1992(a)).

However, the reduced pulse velocity observed in MS60 to MS100 specimens suggests the presence of voids between the two different fine aggregates, indicating medium homogeneity. Therefore, the results from the destructive tests align closely with those from the non-destructive tests. Overall, the UPV results indicate that marine sand replacement up to 60% does not adversely affect the internal quality of concrete. These results confirm that, when utilized within specified replacement limitations, washed marine sand can be a suitable partial replacement for fine aggregate.

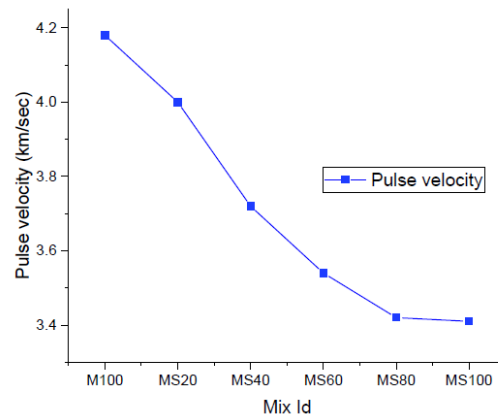


Figure 12. UPV test results

The observed UPV reflects in relation to concrete density, pore structure refinement, and internal micro-cracking behaviour. From the literature Indhumathi *et al.* (2023) observed that the reduced pulse velocity in the case of D40 to D60 specimens due to voids and current research influence of particle morphology, gradation, and ITZ characteristics on both destructive and non-destructive test results.

Workability of Concrete

The slump values for six samples of different mixes are 6 cm, 6.8 cm, 7.1 cm, 7.5 cm, 7.8 cm, and 8.3 cm, respectively, according to IS 1199-1959 (Bureau of Indian Standards, 1959a). These results indicate that the concrete's workability meets the

Table 7. Ultrasonic Pulse Velocity Test Results

S. No.	Mix Identity	Time (μ Sec)	Distance travelled (m)	Pulse Velocity (km/sec)	Quality
1.	M100	36.2	0.15	4.18	Good
2.	MS20	37.5	0.15	4.00	Good
3.	MS40	36.3	0.15	3.72	Good
4.	MS60	35.1	0.15	3.54	Good
5.	MS80	34.2	0.15	3.42	Medium
6.	MS100	34.1	0.15	3.41	Medium

required standards, even with up to 100% replacement of conventional sand with marine sand (MS), as outlined in IS 456:2000 (Bureau of Indian Standards, 2000). Despite the smaller particle size, the workability was not adversely affected. This is due to the marine sand's higher proportion of finer particles, which contributed to enhanced concrete strength by filling voids within the mix.

Mechanical Properties of Concrete

Compressive Strength of Concrete

From the experimental tests of compressive strength, the data reveal a decline in strength beyond the MS60 mix. The binding qualities of the fine aggregates were greatly impacted by the use of MS and M-Sand in the preparation of all mixes in accordance with the mix design. In comparison to the control concrete, both the M100 and MS20 to MS60 mixes showed encouraging results, with the best strength attained at up to 60% MS replacement. This is true even though MS contains a larger percentage of tiny particles, which fill in the concrete's spaces and help it develop strength. For preventing corrosion and the effects on the environment highlight the need for marine sand to be properly cleaned, desalinated, and quality controlled before being used in reinforced concrete applications. The experimental findings are displayed as mean values with ± 1 standard deviation error bars. Incorporating variability measurements enhances the data's dependability and verifies the statistical consistency of the observed trends. While slightly more variation at higher replacement levels may be caused by heterogeneity in marine sand characteristics, lower variability in MS40 and MS60 mixtures suggests homogeneous material behavior.

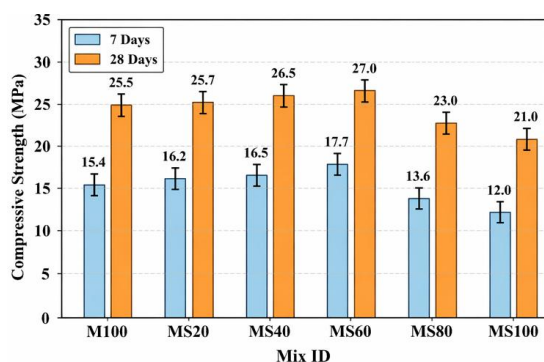


Figure 13. Compressive Strength of Concrete with error bar

Figure 13 clearly reveal that the samples of concrete MS20, MS40, and MS60 compressive strength increased by 0.8%, 3.9%, and 5.9%, respectively. This enhancement is due to the smaller particles of marine sand, which assist fill cavities

and increase the strength of concrete. Better particle packing and void-filling effects brought about by the presence of finer marine sand particles are responsible for the strength increase of up to 60% when marine sand replacement is used. A denser cementitious matrix and better interfacial adhesion between aggregates and paste are two benefits of these smaller particles. However, a decrease in compressive strength was noted at both curing ages when the replacement amount (MS80 and MS100) above 60%. Hence, based on the experimental and theoretical investigation 60 % replacement is optimal value.

According to Karthikeyan & Nagarajan (2016), M30 concrete's compressive strength increases up to 15% when micro silica is replaced; after 20% replacement, Anbarasan & Soundarapandian (2020) find that the values start to decline.

The values start to increase at 80 % and 100 % when the mixes have the same amount of fly ash, Ground Granulated Blast-furnace Slag, sodium hydroxide molarity and alkaline liquid, as observed by Adnan Parung *et al.* (2017).

Split Tensile Strength of Concrete

Figure 14 illustrates that due to the small particle size of MS, the mixes conventional and 20% to 60% replacement of MS yielded excellent results, with only slight differences observed between the MS20, MS40, and MS60 mixes. With the exception of the MS80 and MS100 cylindrical specimens, all other mixes presented a slight increase in tensile strength compared to the control specimen. The MS60 mix demonstrated the highest tensile strength at 3.4 N/mm².

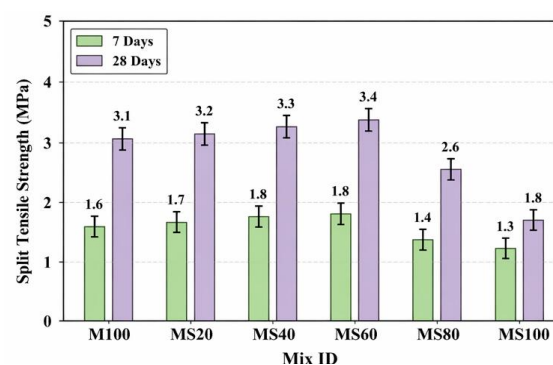


Figure 14. Split Tensile Strength with error bar

The MS20, MS40, and MS60 samples' above strength has improved by 3.2%, 6.5%, and 9.7%, respectively. Furthermore, compared to MS20, the strength of the MS40 and MS60 samples has grown by 3.1% and 6.3%, respectively. The results show that the finer MS particles are more resilient to the spread of cracks.

According to the findings of Pranavan & Srinivasan (2021), the difference in values between the M100 and MS100 samples is 0.25 N/mm² and 0.67 N/mm², respectively. Similar studies by Karthikeyan & Nagarajan (2016) verify the fact that, with more than 50% of replacement of sea sand, the value decreases.

Flexural Strength of Concrete

Prism specimens of dimensions 10 cm × 10 cm × 50 cm were cast to measure the flexural strength. A constant loading rate of 180 kg/min was maintained throughout the experiment. The variation in the flexural strength of the prisms is illustrated in Figure 15.

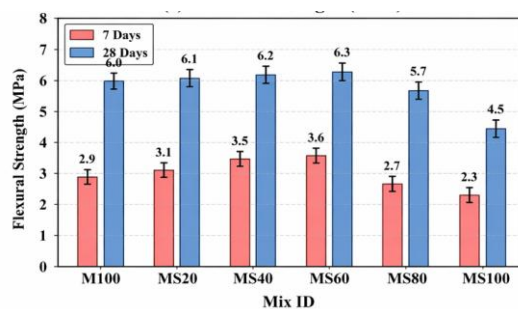


Figure 15. Flexural strength of concrete with error bar

Bending and compressive strength have comparable behavior characteristics. Beyond MS60, the values drop. The M100 and MS20 to MS60 mixtures all yielded good results. Cracking was discovered in the prism's tension zone. The MS20, MS40, and MS60 specimens have slightly higher flexural strength than M100. This can be ascribed to the use of MS as an aggregate, which helps resist crack propagation in the paste.

Compared to the control concrete, the MS20, MS40, and MS60 mixes enhanced their flexural strength by 1.7%, 3.3%, and 5.0%, respectively. The necessary flexural strength is satisfied by the mixture of cement paste, M-Sand, and cleaned sea sand.

Theoretical Investigation

Regression Analysis

Regression equations were developed based on the experimental findings for flexural strength, split tensile strength, compressive strength, and non-destructive testing and presented in Table 8.

It is observed that, the R² values fall between 0.61 to 0.97, indicating that there is little discrepancy between the theoretical and experimental values.

The relationships between crushing strength and split tensile strength, crushing strength and bending strength, crushing strength and hardness, as well as compressive strength and UPV, were derived through regression analysis from the experimental results. These relationships are illustrated in Figure 16, Figure 17, Figure 18 and Figure 19. From this study a comparison is made between theoretical and experimental results. Experimental flexural strength of concrete values are higher when compared with the IS456 - 2000 theoretical flexural strength (0.7 √f_{ck}) of 3.5 N/mm². Overall, the regression analysis validates the validity of the experimental results within the examined replacement levels and verifies the consistency between destructive and non-destructive test results.

The improvement in strength at lower to moderate marine sand replacement levels due to particle packing density, where finer marine sand particles fill micro-voids between cement paste and aggregates.

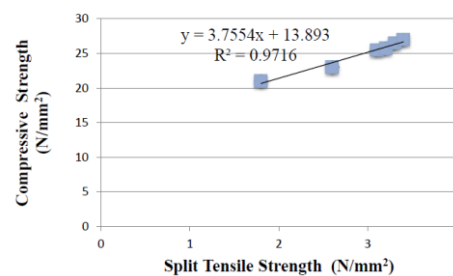


Figure 16. Compressive strength Vs Split tensile strength

Table 8. Regression analysis equations and coefficients

S. No.	Identification	Equation	Coefficient of correlation R ²
1.	Compressive strength Vs Split tensile strength	y = 3.7554x + 13.893	0.972
2.	Compressive strength Vs Flexural strength	y = 3.2634x + 5.8557	0.893
3.	Compressive strength Vs Hardness	y = 1.0464x - 2.9323	0.614
4.	Compressive strength Vs Ultrasonic Pulse Velocity	y = 3.73 x + 10.939	0.665

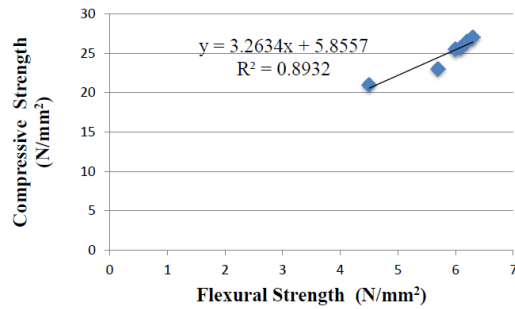


Figure 17. Compressive strength Vs Flexural strength

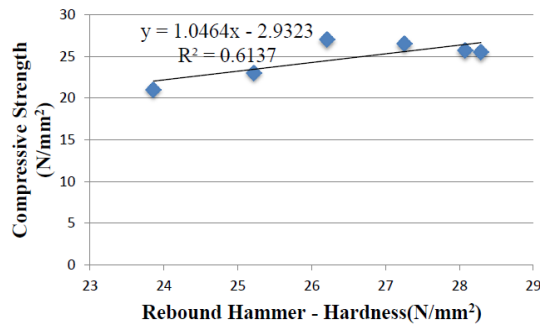


Figure 18. Compressive strength Vs Hardness

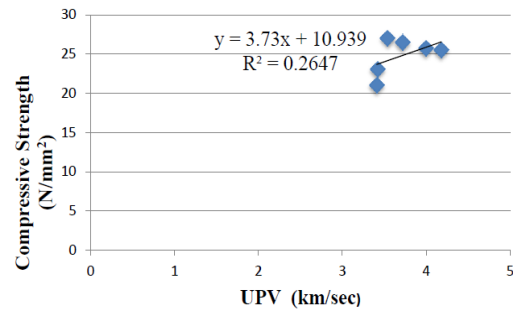


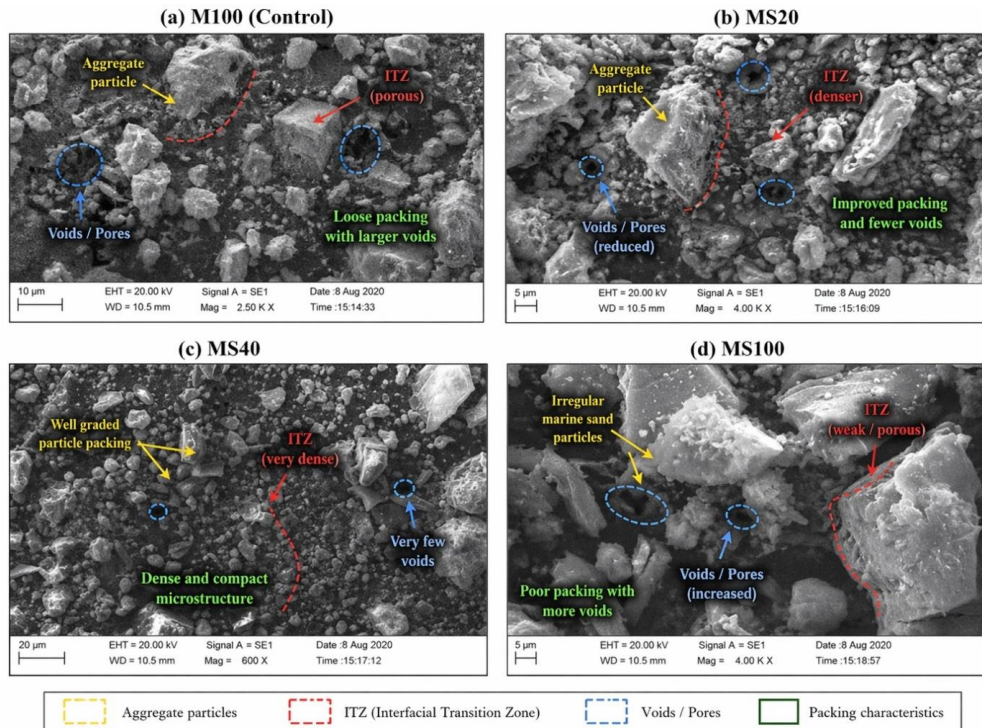
Figure 19. Compressive strength Vs UPV

The reduction in strength at higher replacement levels is attributed to weaker interfacial transition zone (ITZ) due to residual salt content and increased surface smoothness of marine sand particles as per the theoretical and experimental investigation.

Micro structural properties

SEM analysis

In order to view the microstructure of the hydrated cement paste, the concrete's microstructure was examined. Concrete sample M100, MS20, MS40, and MS100 were subjected to SEM analysis. Figure 20 (a), (b), (c), and (d) show the SEM images, respectively.



From M100 → MS20 → MS40: packing becomes denser, ITZ improves, and voids reduce.
At MS100: irregular particles and impurities lead to weak ITZ and more voids.

Figure 20. SEM analysis

With finer particles occupying the gaps between bigger aggregates, the MS20 mix exhibits better particle packing. There are fewer apparent pores and the ITZ seems denser and more coherent, better mechanical properties are a result of this better microstructure. Out of all the mixes, the MS40 mix exhibits the most compact and well-graded microstructure. With a reduced ITZ gap between the aggregates and the matrix, the matrix seems to be well formed and has a better compressive strength. While the hydration process in the mix MS100 was almost the same as that of a control concrete, the amount of calcium silicate hydrate gel produced in the mix was much lower than that of M100. Because of the binding between the cement particles, it is clear from the data that MS operates better. As the percentage of MS rises, the mix's packing density gets better. The results show that the strength and microstructural behavior of the concrete are improved when M-Sand and MS are used in place of conventional concrete materials.

SEM research shows that the bonding between fine aggregates and cement is well-formed, with a decreased ITZ gap between the aggregates and the matrix, leading to an increase in compressive strength. This is made possible by the MS's flat surface, which strengthens the bond between the material particle and the hydration gel.

From the SEM analysis results, MS20 and MS40 mixes exhibit improved particle packing and a denser ITZ, which aligns with higher strength values. MS100 shows increased porosity and weaker ITZ, explaining the reduction in strength.

Conclusions

The results indicate that the workability of fresh concrete increased with an increase in marine sand content up to 60%, which may be attributed to the relatively finer particle size of the marine sand used in this study. Under the specific material properties and mix proportions adopted, all investigated replacement levels (20%, 40%, and 60%) satisfied the target compressive strength requirements for M25 grade concrete (Ganesan *et al.*, 2022).

Among the tested mixes, concrete with 60% marine sand replacement exhibited higher compressive strength, split tensile strength, and flexural strength compared to the control mix. This improvement is attributed to the enhanced particle packing effect resulting from the higher proportion of fine particles in marine sand, which contributed to improved matrix densification under laboratory conditions. It is observed that fine aggregate replacement up to 60% with marine sand met the

strength criteria for the tested grade of concrete (Ganesan *et al.*, 2025).

Non-destructive test results, including ultrasonic pulse velocity measurements, showed higher pulse velocity values for the 60% marine sand mix, indicating a comparatively denser and well-compacted concrete for the specimens tested. These observations are consistent with the trends obtained from destructive strength tests, within the limitations of the experimental program.

Overall, the findings of this study demonstrate that, for M25 grade concrete prepared using the selected materials and curing conditions, partial replacement of M-Sand with washed marine sand up to 60% can achieve the required fresh and mechanical properties. However, these conclusions are limited to short-term mechanical performance and laboratory-controlled conditions. Long-term durability, corrosion performance of reinforcement, and field-level applicability were not investigated and require further experimental validation. Future studies may focus on durability-related aspects, including corrosion behaviour using appropriate protective measures, to assess the broader applicability of marine sand concrete.

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Author Contribution

Karthikeyan Ganesan: Conceptualization, Methodology, Investigation, Writing – Original Draft.

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Ethical Approval and Consent to Participate

Not applicable

Declaration of Generative AI Use

The authors declare that no Generative AI tools were used in the preparation of this manuscript.

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References

- Adnan Parung, H., Tjaronge, M. W., & Djamaluddin, R. (2017). Compressive strength of marine material mixed concrete. *IOP Conference Series: Materials Science and Engineering*, 271(1), Article 012066. <https://doi.org/10.1088/1757-899X/271/1/012066>
- Ahmed, A., Guo, S., Zhang, Z., Shi, C., & Zhu, D. (2020). A review on durability of fiber reinforced polymer (FRP) bars reinforced seawater sea sand concrete. *Construction and Building Materials*, 256, Article 119484. <https://doi.org/10.1016/j.conbuildmat.2020.119484>
- Al-Fakih, A., Hashim, M. H. M., Alyousef, R., Mutafi, A., Abo Sabah, S. H., & Tafsirojjaman, T. (2021). Cracking behavior of sea sand RC beam bonded externally with CFRP plate. *Structures*, 33, 1578-1589. <https://doi.org/10.1016/j.istruc.2021.05.042>
- Anbarasan, I., & Soundarapandian, N. (2020). Investigation of mechanical and microstructural properties of geopolymer concrete blended by dredged marine sand and manufactured sand under ambient curing conditions. *Structural Concrete*, 21(3), 992-1003. <https://doi.org/10.1002/suco.201900343>
- Ashwini, L., & Kiran, S. (2018). Use of sea sand in partial replacement of river sand in concrete for construction. *International Journal of Innovative Science, Research and Technology*, 3(6), 453-455.
- ASTM International. (2017). *Standard test method for splitting tensile strength of cylindrical concrete specimens (ASTM C496/C496M-17)*.
- Balaji, G., & Vetturayasudharsanan, R. (2020). Experimental investigation on flexural behaviour of RC hollow beams. *Materials Today: Proceedings*, 21, 351-356. <https://doi.org/10.1016/j.matpr.2019.05.461>
- Bayesteh, H., Sharifi, M., & Haghsheenas, A. (2020). Effect of stone powder on the rheological and mechanical performance of cement-stabilized marine clay/sand. *Construction and Building Materials*, 262, Article 120792. <https://doi.org/10.1016/j.conbuildmat.2020.120792>
- Bureau of Indian Standards. (1959a). *Methods of sampling and analysis of concrete (IS 1199)*.
- Bureau of Indian Standards. (1959b). *Methods of tests for strength of concrete (IS 516; reaffirmed 2018)*.
- Bureau of Indian Standards. (1992a). *Method of non-destructive testing of concrete, Part 1: Ultrasonic pulse velocity (IS 13311, Part 1)*.
- Bureau of Indian Standards. (1992b). *Non-destructive testing of concrete: Methods of test, Part 2: Rebound hammer (IS 13311, Part 2)*.
- Bureau of Indian Standards. (1999). *Splitting tensile strength of concrete—Method of test (IS 5816)*.
- Bureau of Indian Standards. (2000). *Plain and reinforced concrete—Code of practice (IS 456)*.
- Bureau of Indian Standards. (2009). *Concrete mix proportioning—Guidelines (IS 10262)*.
- Bureau of Indian Standards. (2013). *Ordinary Portland cement—53 grade—Specification (IS 12269)*.
- Bureau of Indian Standards. (2016). *Specification for coarse and fine aggregates from natural sources for concrete (IS 383)*.
- Chen, Z., Li, S., Zhou, J., Xu, R., & Dai, S. (2022). Flexural behavior of GFRP bars reinforced seawater sea sand concrete beams exposed to marine environment: Experimental and numerical study. *Construction and Building Materials*, 349, Article 128784. <https://doi.org/10.1016/j.conbuildmat.2022.128784>
- Dang, V. Q., Ogawa, Y., Bui, P. T., & Kawai, K. (2021). Effects of chloride ions on the durability and mechanical properties of sea sand concrete incorporating supplementary cementitious materials under an accelerated carbonation condition. *Construction and Building Materials*, 274, Article 122016. <https://doi.org/10.1016/j.conbuildmat.2020.122016>
- Dhondy, T., Remennikov, A., & Sheikh, M. N. (2019). Benefits of using sea sand and seawater in concrete: A comprehensive review. *Australian Journal of Structural Engineering*, 20(4), 280-289. <https://doi.org/10.1080/13287982.2019.1659213>
- Dhondy, T., Remennikov, A., & Sheikh, M. N. (2020). Properties and application of sea sand in sea sand-seawater concrete. *Journal of Materials in Civil Engineering*, 32(12), Article 04020392. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0003475](https://doi.org/10.1061/(ASCE)MT.1943-5533.0003475)
- Dong, Z., Wu, G., Zhao, X. L., Zhu, H., & Lian, J. L. (2018). Durability test on the flexural performance of seawater sea-sand concrete beams completely reinforced with FRP bars. *Construction and Building Materials*, 192, 671-682. <https://doi.org/10.1016/j.conbuildmat.2018.10.166>
- Feng, B., Liu, J., Wei, J., Zhang, Y., Chen, Y., Wang, L., Chen, Y., & Sun, Z. (2021). Research on properties and durability of desalinated sea sand cement modified with fly ash. *Case Studies in Construction Materials*, 15, e00675. <https://doi.org/10.1016/j.cscm.2021.e00675>
- Ganesan, K., Kanagarajan, V., & Dominic, J. R. J. (2022). Influence of marine sand as fine aggregate on mechanical and durability properties of cement mortar and concrete. *Materials Research Express*, 9(3), Article 035503. <https://doi.org/10.1088/2053-1591/ac5f88>
- Ganesan, K., Kanagarajan, V., & Dominic, J. R. J. (2025). Investigation on corrosion and flexural behaviour of reinforced concrete using marine sand. *Jurnal Teknologi (Sciences & Engineering)*, 87(1), Article 22209. <https://doi.org/10.11113/jurnalteknologi.v87.22209>
- Helal, J., Sofi, M., & Mendis, P. (2015). Non-destructive testing of concrete: A review of methods. *Electronic Journal of Structural Engineering*, 14(1), 97-105. <https://doi.org/10.56748/ejse.141931>
- Indhumathi, M., Ragavan, V., Dhanalakshmi, A., & Lydia, D. H. (2023). A study on non-destructive tests and flexural strengths of geopolymer concrete using combination of different fine aggregates. *E3S Web of Conferences*, 387, Article 04001. <https://doi.org/10.1051/e3sconf/202338704001>
- Kandou, C., Tumpu, H. T., Tumengkol, T., & Kabo, D. R. G. (2025). Performance evaluation of self-compacting concrete (SCC) using sea sand and seawater as sustainable constituents. *UNEC Journal of Engineering and Applied Sciences*, 5(2), 58-74. <https://doi.org/10.61640/ujes.2025.1205>
- Karthikeyan, M., & Nagarajan, V. (2016). Feasibility study on utilization of marine sand in concrete for sustainable development. *Indian Journal of Geo-Marine Sciences*, 45(2), 313-318.
- Leema Margaret, A., Karthikeyan, G., Ajandhadevi, S., Jenitha, G., & Subalakshmi, M. (2023). Numerical study on flexural behavior of reinforced concrete beam using MATLAB. *AIP Conference Proceedings*, 2831, Article 060004.
- Liu, J., Ju, B., Xie, W., Yu, H., Xiao, H., Dong, S., & Yang, W. (2021). Design and evaluation of an ultrahigh-strength coral aggregate concrete for maritime and reef

- engineering. *Materials*, 14(19), Article 5871. <https://doi.org/10.3390/ma14195871>
- Pranavan, S., & Srinivasan, G. (2021). Investigation on behaviour of M-sand and sea sand based concrete. *Materials Today: Proceedings*, 45(7), 7079-7085. <https://doi.org/10.1016/j.matpr.2021.01.930>
- Sun, C., Xin, M., & Wang, X. (2025). Study on mechanical properties and anti-erosion performance of fiber-reinforced seawater sea sand concrete. *European Journal of Environmental and Civil Engineering*, 29(4), 785-808. <https://doi.org/10.1080/19648189.2024.2416451>