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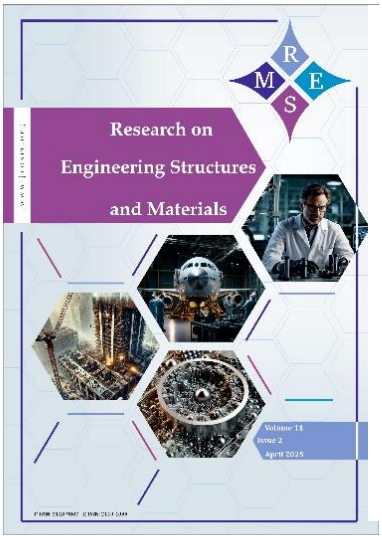

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Online Publication Date: 10 April 2025
URL: http://www.jresm.org/archive/resm2025-665ma0206rs.html
DOI: http://dx.doi.org/10.17515/resm2025-665ma0206rs

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article
Benhaddou K, Souileh A, Ouadif L, Mabrouk A, Abdelhak S, Baba K, Rharouss M. Valorization of marine dredged sediments from Jebha Port as a sustainable alternative to dune sand in concrete manufacturing. *Res. Eng. Struct. Mater.*, 2025; 11(4): 1667-1682.

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Research Article

Valorization of marine dredged sediments from Jebha Port as a sustainable alternative to dune sand in concrete manufacturing

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Article Info

Article History:

Received 06 Feb 2025
Accepted 04 Apr 2025

Keywords:

Ecological alternative; Dredged sediments; Physico-chemical characterization; Progressive incorporation; Mechanical and rheological performance; Concrete formulation

Abstract

The construction industry is facing increasing challenges due to the depletion of natural sand resources, making it essential to find sustainable alternatives. This study explores the potential of marine dredged sediments from Jebha Port, Morocco, as a substitute for dune sand in B30 concrete. By incorporating these sediments at different replacement levels (10% to 100%), the study evaluates their impact on the concrete's workability and strength. To start, a detailed physico-chemical analysis of the dredged sediments was carried out to understand their properties and how they might affect concrete performance. The sediments were then mixed into concrete at varying substitution rates, from small adjustments (10% and 25%) to complete replacement of dune sand (100%). The fresh-state properties showed that higher sediment content reduced workability, making the mix less fluid. However, with proper adjustments to the mix design, this issue could be managed. The study also examined the hardened-state performance, focusing on compressive and tensile strength. Results showed that replacing up to 25% of dune sand with marine sediments maintained acceptable strength, making the concrete suitable for non-structural applications. Beyond this level, mechanical performance declined, suggesting that total replacement may require further optimization. Overall, this research highlights those marine dredged sediments from Jebha Port can be a practical and eco-friendly alternative to natural dune sand. By reusing these sediments in construction, we can reduce environmental pressure on sand resources while promoting more sustainable building practices. This approach aligns with circular economy principles, turning what was once considered waste into a valuable material for the construction industry.

1. Introduction

In Morocco, large quantities of materials must be dredged annually from seaports, rivers, and lakes to maintain maritime navigation safety, ensure port accessibility, facilitate port infrastructure operations, and optimize the use of extracted sediments. According to the National Ports Agency, around 3 million cubic meters of sediments are dredged annually, with over 70% comprising sand

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DOI: http://dx.doi.org/10.17515/resm2025-665ma0206rs

- equivalent to more than 2 million cubic meters - mainly extracted from ports in Morocco's southern regions. [1] The issue of sediment accumulation is particularly prevalent in Atlantic coastal ports, especially in the central and southern sectors, spanning from Safi to Dakhla, where the highest dredging volumes are recorded.[2]

Currently, dredged sediments, particularly sand, are being investigated as a sustainable industrial alternative to conventional sand extraction. This approach aligns with public policies aimed at mitigating the challenges posed by the informal sector, which predominantly depends on the exploitation of beaches and dunes. [3] A key initiative in this context is the "Le Sable Vert" label, which fosters sustainability by incorporating environmental, social, and economic factors into the extraction and valorization of dredged materials. This shift has motivated professionals in the construction and public works (BTP) sector, both in Morocco and globally, to explore innovative solutions. As a result, there has been a growing body of research dedicated to the valorization of marine sediments as alternative construction materials, aiming to mitigate the depletion of natural resources, meet the rising demand for construction materials, and diversify supply sources.[4]

The incorporation of marine sediments into concrete has been widely explored in civil engineering, as concrete continues to be the most commonly used construction material globally. Research has primarily examined the substitution of conventional concrete components with dredged sediments, either as a replacement for cement or sand, and investigated the feasibility of replacing a portion of CEM I 52.5 cement with an equivalent volume of dried and ground dredged sediments from the Port of Dunkirk, France. Similarly, Hayek (2022)[5] investigated the valorization of marine sediments extracted from the ports of Pérols and Camargue, France, evaluating the partial replacement of sand with raw or pre-treated sediments in XS C30/37-class ordinary concrete formulations.

In this context, the present study investigates the effects of incorporating marine dredged sediments from the Port of Jebha on the mechanical and rheological properties of B30 concrete. To achieve this, dune sand in the reference mix was partially or fully replaced with dredged sediments at replacement rates ranging from 10% to 100%. A preliminary physico-chemical characterization of the sediments confirmed their suitability for use without the need for specific pre-treatment. The sediments were classified into two categories: C1 (cleaner sediments) and C2 (less clean sediments). Two concrete formulations incorporating these sediments were then tested to assess their impact on key properties, including workability (slump), compressive strength, and tensile strength.[6] Therefore, the valorization of dredged sediments represents a promising solution for concrete production, serving as a sustainable substitute for conventional sand. However, careful selection of processing methods and incorporation rates is essential to ensure adherence to regulatory standards and to preserve the optimal performance of the material.[7]

The use of dredged sediments as a substitute for dune sand offers an environmentally sustainable solution by decreasing dependence on natural dune ecosystems, which are vital for coastal preservation. This approach also tackles the challenge of managing dredged material waste by repurposing it for construction purposes, thus reducing the volume of materials either disposed of at sea or stored on land.[8]

This study evaluates the impact of marine dredged sediments from Jebha Port, Morocco, as partial or full replacements for dune sand in B30 concrete, focusing on their impact on workability and mechanical performance. By valorizing these materials, this study aligns with environmental policies aimed at lowering the ecological footprint of construction industries. It aligns with circular economy principles by reintegrating an industrial by-product into the lifecycle of construction materials. These initiatives contribute to the conservation of natural resources and help mitigate the environmental degradation associated with traditional sand extraction practices.[9]

1.1 Dredging Site

The sediments examined in this study were extracted from the port of Jebha, situated in northern Morocco, within the province of Chefchaouen in the Tanger-Tétouan-Al Hoceima region, as shown in Figure 1. The port of Jebha plays a crucial role in fishing activities and maritime trade. Located 162 km from Al Hoceima, it is accessible via the Mediterranean coastal road, which connects

Tétouan to Al Hoceima. Positioned between the limestone cliffs of Pointe des Pêcheurs and the Oued Misiaba, the port enjoys natural protection against ocean swells.[10]

This port is an essential economic driver for the region, facilitating the transport of goods and fishery products. Its approximate coordinates are 35°13'10" N and 4°40'45" W, giving it a strategic position along the Moroccan Mediterranean coastline.

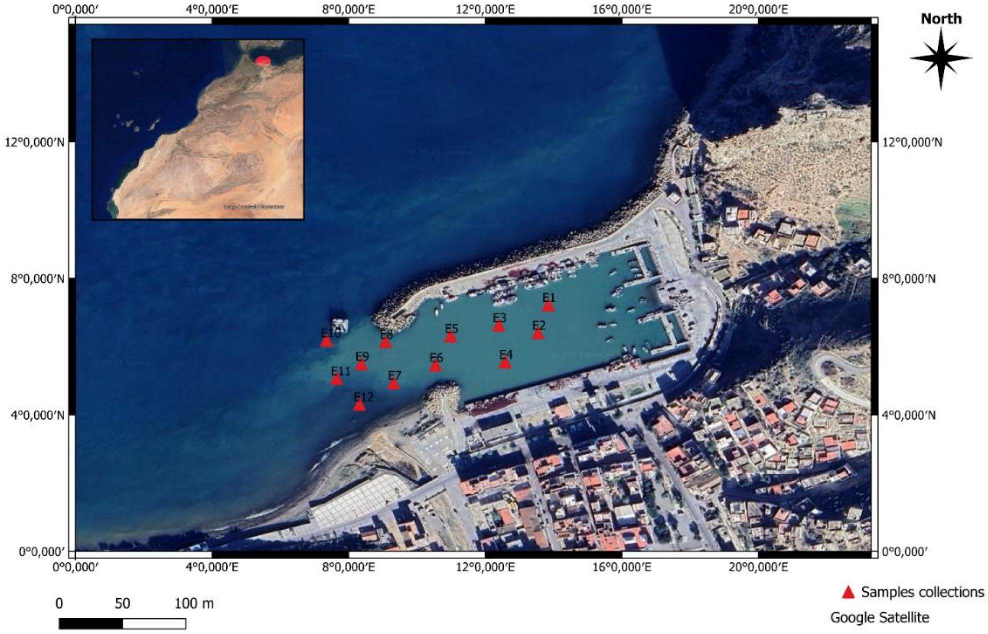

Fig. 1. Map showing the location of the dredging site at Jebha Port

2. Materials and Methods

Figure 2 illustrates the methodology employed in this study, outlining the key steps involved in evaluating the use of dredged sediments as a substitute for sand in concrete. These steps include sediment collection, physical, chemical, and mineralogical characterization, concrete formulation with varying substitution levels, and subsequent rheological and mechanical testing.

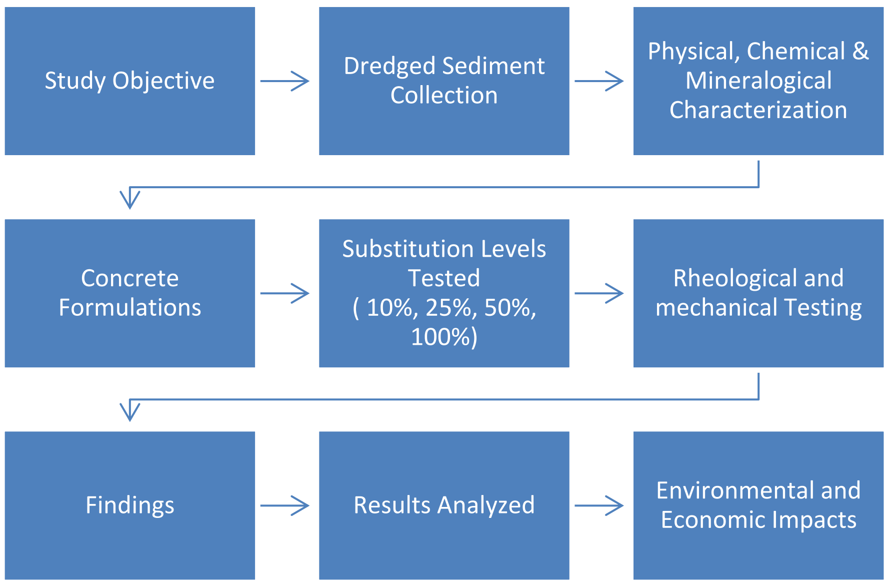

Fig. 2. The process of dredged sediment utilization in concrete production

Finally, the results are analysed to assess the performance of the material and evaluate its practical applications.[11,12]

2.1 Materials

The cement used in this study is a Portland cement, produced by grinding clinker that contains at least 65% clinker, with additional additives such as limestone or fly ash. This cement is sourced from the NOVACIM plant. The limestone aggregates, including crushed sand (0/4 mm), Gravel G0 (4/8 mm), and Gravel G1 (8/16 mm), are supplied by the Carritek quarry, located on the northern bank of the Oued Cherrate in the province of Skhirat, while the dune sand (0/1 mm) originates from the Souiria region. [13,14]

These granular fractions underwent identification tests in accordance with Moroccan standard NM 10.1813.[13] The crushed sand fraction (0-4 mm) and the dune sand fraction (0-1 mm) were subjected to physico-mechanical characterization tests. The dune sand demonstrates complementary properties when combined with coarse sand (0-4 mm). As such, their mixture (30% dune sand and 70% crushed sand) satisfies the requirements outlined in standard NM 10.1.813.[14] The identification characteristics of the dune sand are summarized in the following table;

Table 1. Results of identification tests for dune sand 0-1 mm

Designation	%< 0,25	%< 1	%< D= 1 mm	%< 1,4D= 1,25 mm	%< 2D= 2 mm	ES	MF	Soluble Sulfate in Acid (% SO_3)	Water-Soluble Chloride (% Cl^-)	Sulfide Content (S^{2-})
Result	63	99	99	100	100	74	1.32	0.019	0.001	0.022

The sediments used in this study were extracted from dredged materials at the port of Jebha. Twelve samples were collected from various points within the port. Initially in the form of sludge, these sediments were dried at 105°C in an oven to stabilize their mass, remove their water content, and prevent the need for subsequent mass corrections during incorporation into concrete. After drying, the samples were sieved at 2 mm to ensure a grain size comparable to that of the dune sands being substituted.[15]

(a) (b) (c)

Fig. 3. Stages of marine dredged sediment collection and processing: (a) excavator scooping dredged sediment from the water at the port, (b) sediment samples placed inside a drying oven for moisture removal, (c) weighing the dried sediment using a balance scale

2.2 Experimental Techniques

2.2.1 Sediment Characterization

The materials used in this study were thoroughly characterized using both physical and chemical methods. Particle size analysis was performed using two techniques: dry sieving after washing, in accordance with the standard NM 00.8.082, and an additional method to ensure comprehensive analysis,[16] and sedimentation particle size analysis with a deflocculant, in compliance with standard NM 00.8.083.[17] Cleanliness tests were assessed through the measurement of the sand equivalent at 10% fines NM 10.1.732,[18] and the methylene blue test.

The organic fraction of the sediments was also determined according to standard XP P94-055,[19] and the total organic carbon content was measured in compliance with standard NM EN 13639.[20] Chemical analysis was performed using X-ray fluorescence spectrometry NM 10.1.005,[21] allowing for the determination of elemental concentrations. The carbonate content (% $CaCO_3$) was evaluated following NF 94-048,[22] the pH was measured according to NF ISO 10390,[23] and the loss on ignition at 1000°C was determined in accordance with NM 10.1.005.[21] Additionally, a mineralogical analysis of the JEBHA sediments was conducted using X-ray diffraction (XRD), The sediment samples for XRD analysis were collected from various depths, ranging from 0-10 cm to 30-40 cm, ensuring representative sampling for each sediment type. under standard conditions, as well as after two specific treatments: ethylene glycol saturation and heating at 550°C.[24] These analyses aimed to identify the mineralogical composition and the crystalline phases present. The identification was carried out using EMPYREAN (reflection-transmission Spinner configuration, MALVERN PANALYTICAL) and X'PERT PRO (reflection-transmission configuration, PANALYTICAL) instruments.[25]

2.2.2 Concrete Formulation

The study examined nine concrete formulations, including a reference mix, all designed using the Dreux-Gorisse method. In these formulations, the dune sand in the reference mix was replaced with untreated dredged sediments from the port of Jebha, used as granular correctors. The substitution rates for the dune sand were set at 10%, 25%, 50%, and 100%.[26]

Table 2. Components of 1 m^3 of concrete incorporating sediments from the port of Jebha at different substitution percentages

Sediment Percentage	RC 0%	10%	25%	50%	100%	10%	25%	50%	100%
		C1	C1	C1	C1	C2	C2	C2	C2
Element									
Gravel G1 (8/16)	530	530.53	530.53	530.53	530.53	530.53	530.53	530.53	530.53
Gravel G0 (4/8)	453	453.45	453.45	453.45	453.45	453.45	453.453	453.45	453.45
Crushed sand (0/4)	639	643.47	647.31	647.31	647.31	646.67	644.112	646.67	647.31
Dune sand	268	259.53	214.27	142.84	0	258.08	220.296	146.46	0
Sediment	0	26.80	67.00	134.00	268	26.80	67	134.00	268
Cement	360	360.00	360.00	360.00	360	360.00	360	360.00	360
Total water	159	135.21	136.44	140.87	159	133.465	133.609	137.89	159
Tempo 25 M admixture (1.9%)	6,84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84
W/C	0,4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
S/G ratio	0,650	0.654	0.658	0.658	0.658	0.657	0.655	0.657	0.658
Density	2,43	2.43	2.43	2.43	2.42	2.45	2.43	2.44	2.42
Concrete temperature (°C)	24	19	21	18.7	18.7	22.5	20.8	21.2	18.5
Ambient temperature (°C)	21	17.6	18.5	18.9	16	18.5	19	21.7	17.2

Slump test by Abrams Cone (mm) at T15min	21	21	20	18	13	19	19	20	12

The formulations included the reference concrete (RC) with 0% substitution, as well as concretes in which dune sand was partially or fully replaced with sediments categorized as type 1 (C1) and type 2 (C2). For category 1, the substitutions were 10% C1, 25% C1, 50% C1, and 100% C1, while for category 2, the substitutions were 10% C2, 25% C2, 50% C2, and 100% C2. The categories C1 and C2 represent two different types of dredged sediments, while the percentages denote the proportion of dune sand replaced by these sediments.[27,28]

Ambient temperature and concrete temperature were measured, and the slump of the concrete was monitored over one hour. Slump values for the different mixes were determined using the Abrams cone test. The table below presents the details of the various formulations, including the quantities of each component in the concrete.[29] The reference concrete (CC) is classified as C30 and exhibits good workability, corresponding to slump class S4 (slump height between 16 and 21 cm). This was achieved using a water-to-cement ratio (W/C=0,4).[30]

2.2.3 Mechanical Strengths

The compression and tensile strength tests were conducted in accordance with Moroccan NM standards, ensuring reliable and standardized evaluation of concrete performance. These tests were carried out on cylindrical specimens (16 cm × 32 cm) to assess the mechanical behavior of concrete incorporating marine dredged sediments. After casting, the specimens were demolded after 24 hours and then stored in water for curing to allow full hydration. The compressive and tensile strength tests were performed at 7 and 28 days, following standard procedures to evaluate the development of mechanical properties over time. This standardized methodology ensures accurate and reproducible results, providing essential insights into the feasibility of using marine dredged sediments as a partial or total replacement for dune sand in concrete production.[31,32]

(a) (b) (c)

Fig. 4. Stages of compressive strength testing of concrete cylinders: (a) concrete cylinders before curing, showing the initial casting, (b) concrete cylinders submerged in water for curing to ensure hydration, (c) concrete cylinders being tested for compressive strength using a hydraulic press

3. Results and Comments

3.1. Sample Preparation

The raw sediments extracted from the port of Jebha underwent a thorough physico-chemical analysis to evaluate their quality and potential for use as a material in concrete. This study aims to investigate their feasibility as a partial or total substitute for dune sand in initial concrete formulations. Following this, an assessment of the mechanical properties of the resulting concrete was conducted to examine the impact of incorporating these sediments on the material's performance in both fresh and hardened states. To ensure granulometric consistency with dune sand, the 12 sediment samples were heated at 100°C for 24 hours in an oven to eliminate excess water, then sieved through a 2 mm mesh. After identification tests, the samples were classified into two distinct categories based on their properties: Category C1 includes materials considered clean (VB index < 2), while Category C2 comprises those deemed less clean (VB index > 2).

3.2. Grain Size Distribution and Physical Properties

The analyzed sediments display a diverse granulometric distribution, ranging from coarse particles (> 20 mm) to fine particles (< 2 µm). Most samples exhibit a balanced particle size distribution, with a predominance of intermediate fractions (between 2 mm and 80 µm). However, certain samples, such as S10, contain a higher proportion of fine particles, whereas others, like S6 and S7, have a greater abundance of coarse particles.

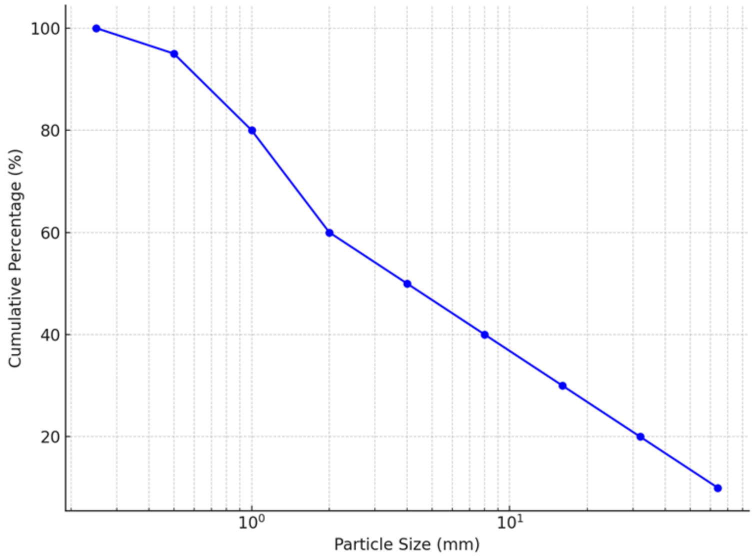

Fig. 5. Particle size distribution curve of dredged sediments from Jebha

3.3. Chemical and Mineralogical Composition

The chemical and mineralogical properties of the sediments were analyzed using X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques, as shown in Figures 7, 8, and 9. The sediments are primarily composed of silicon dioxide (SiO_2), with concentrations varying between 66.46% and 79.01%. Minor components include aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO). The high quartz content reflects low chemical reactivity and excellent stability, making the sediments suitable as a sand substitute in construction applications.

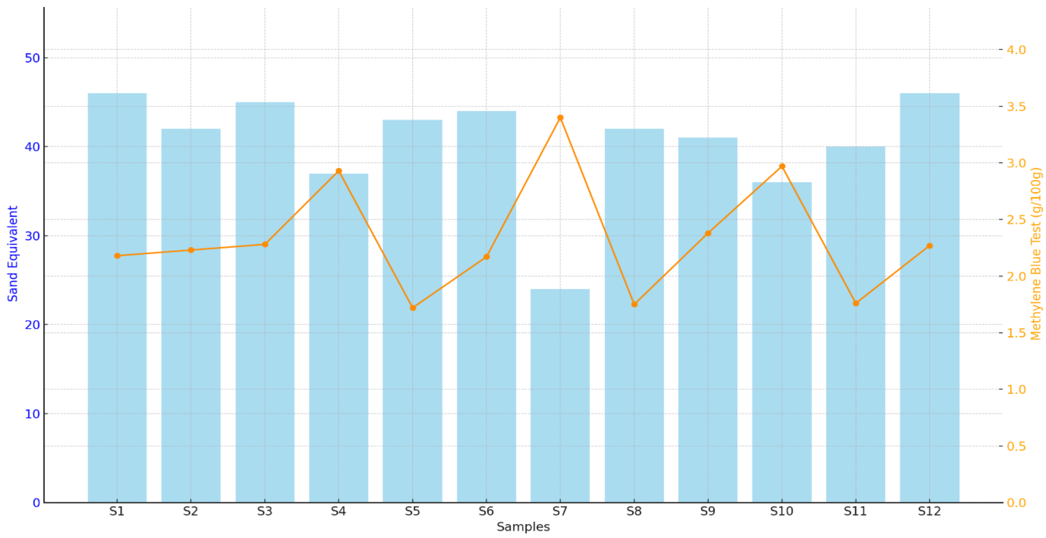

Fig. 6. Test Results for cleanliness: methylene blue value and sand equivalent

The methylene blue test values ranged from 1.72 to 3.40 g/100g, indicating the presence of fine particles that could influence the water demand of the mixtures. Additionally, the sediments exhibited alkaline pH levels, ranging from 8.60 to 9.16, suggesting a low potential for alkali-silica reactivity in concrete. The X-ray diffraction (XRD) analysis was used to characterize three powder samples, labeled XRD1, XRD2, and XRD3, extracted from the sediments of the port of Jebha. These samples were prepared using three different techniques: normal conditions, ethylene glycol saturation, and heating at 550°C.

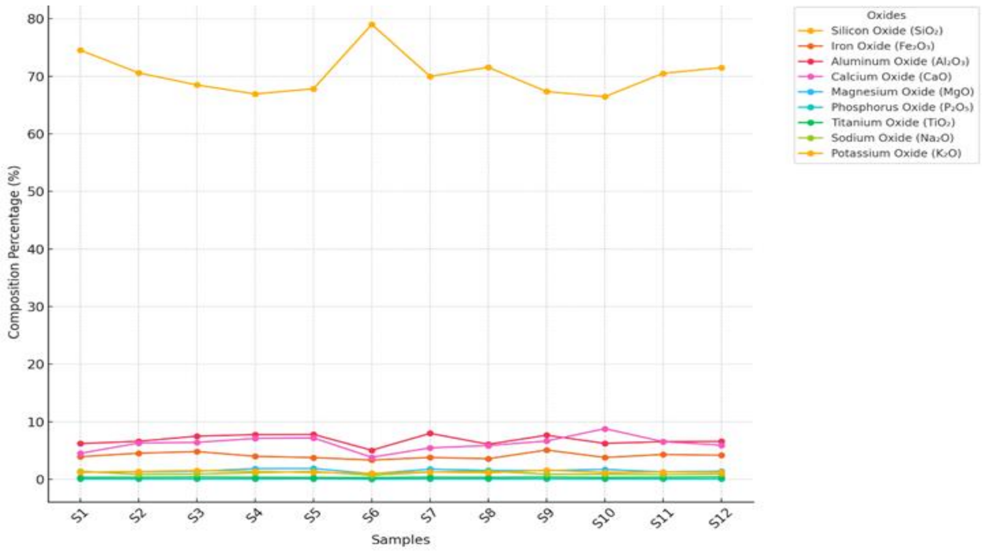

Fig. 7. X-ray fluorescence (XRF) analysis of dredged sediments

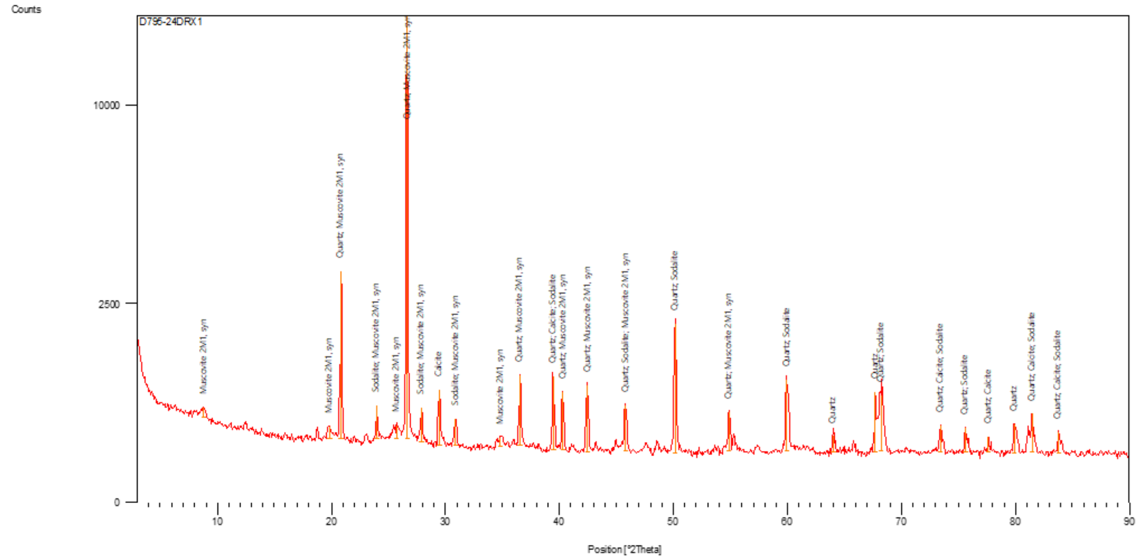

Fig. 8. Powder diffractogram of sample DRX1

The obtained results reveal a composition dominated by stable crystalline minerals, such as Quartz (SiO_2), Calcite ($CaCO_3$), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$), and, in some samples, Sodalite and Clinochlore. These minerals, recognized for their structural stability, showed no significant changes in the diffractograms after treatment, confirming the absence of expandable clay phases such as smectites. The observation of the crystalline phases presents in the sediments highlighted the stability of the minerals: the identified phases, particularly Muscovite and Clinochlore, retain unchanged interlayer distances (d = 10 Å) after ethylene glycol saturation and heating at 550 °C. This indicates a non-expandable structure resistant to thermal or chemical transformations. Quartz and Calcite: These minerals remain unchanged across the three preparation methods, reflecting their chemical inertia and high crystalline stability. The results confirm the absence of sensitive clay phases, such as smectites, which would have shown significant expansion under ethylene glycol. Halite, identified in one sample (XRD3), may indicate an evaporitic origin or saline contamination.

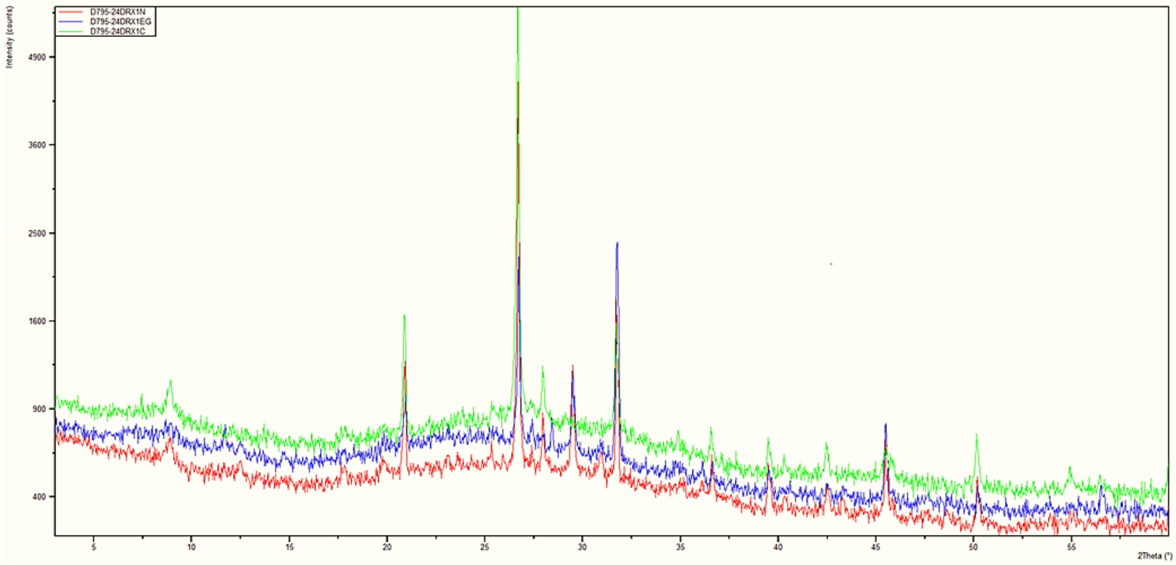

Fig. 9. Identification of clays on oriented slides

3.4. Rheological and Mechanical Properties

The results indicate a gradual decline in concrete slump as the substitution rate of dune sand with dredged sediments from the port of Jebha increases. This reduction is more pronounced for category C2, which has lower cleanliness compared to C1. For C1, the slump remains stable at 21 mm up to a 10% substitution, slightly decreases to 20 mm at 25%, then drops to 18 mm at 50%, and further declines to 13 mm at 100%, reflecting a progressive loss of workability due to the increasing presence of absorbent fines. For C2, the slump is already reduced to 19 mm at 10% and 25%, further decreases to 17 mm at 50%, and reaches 12 mm at 100%, highlighting a more significant impact on workability due to the higher content of fine particles and impurities.

3.5. Compressive Strength

For each test, five specimens were tested daily, and the average compressive strength values were calculated and illustrated in the respective figures. The analysis of the results reveals a gradual decline in compressive strength as the substitution rate of dune sand increases, both at 7 and 28 days. The compressive strength was measured using an average of three samples for each substitution ratio, and the mean values were calculated and represented in the graphs. The control samples (0% substitution) exhibited the highest strength, reaching 57.7 MPa at 28 days. In contrast, full substitution (100%) resulted in a significant reduction in compressive strength, with values of 48.2 MPa for C1 sediments and 48.0 MPa for C2 sediments. At lower substitution rates (10%–25%), the decrease in strength was moderate, indicating that these proportions could be suitable for non-structural applications where high mechanical performance is not a primary requirement.

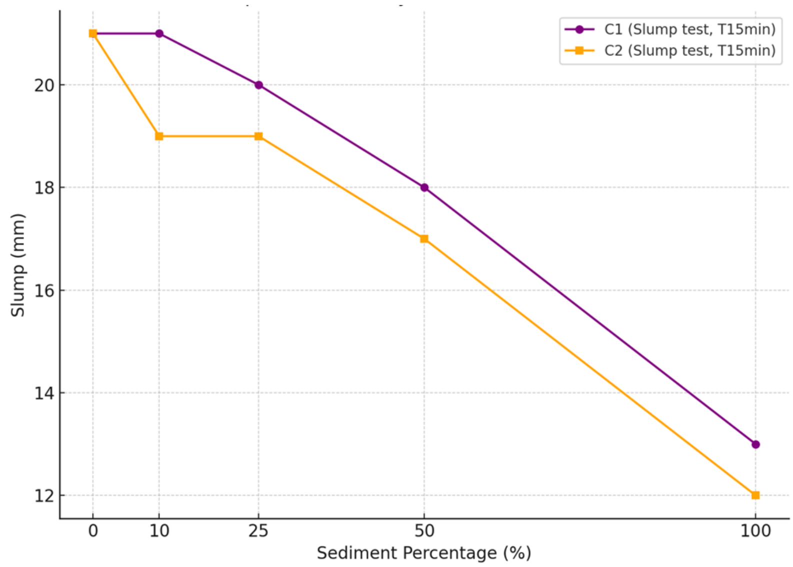

Fig. 10. Slump test result by Abrams Cone at T15 min of concrete with varying substitution ratios of dredged sediments C1 and C2

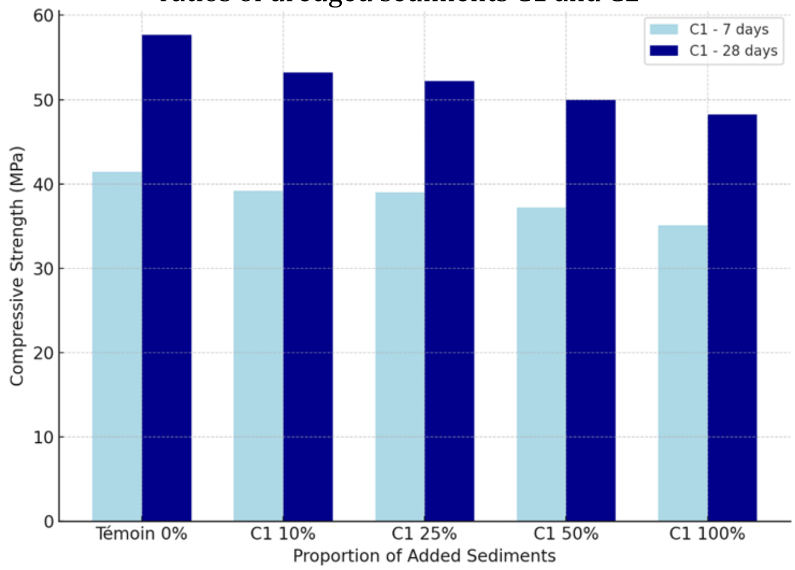

Fig. 11. Compressive strength of concrete with varying substitution ratios of dredged sediments C1

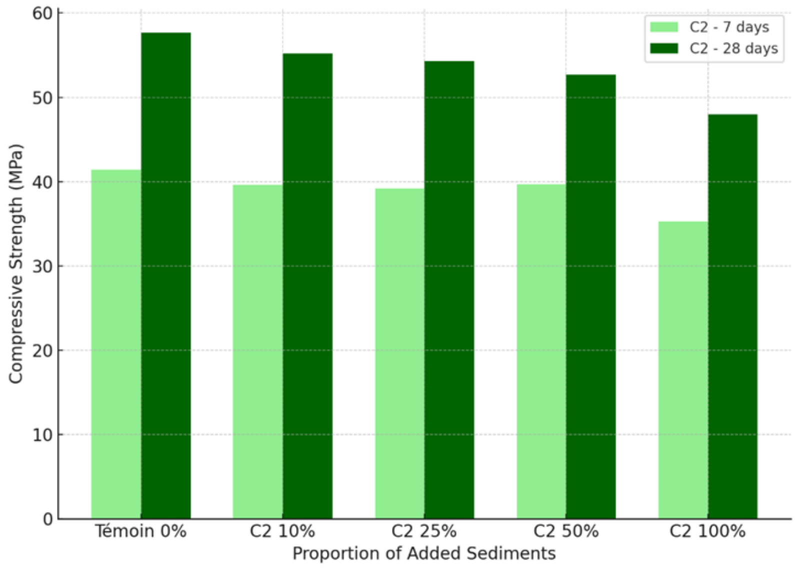

Fig. 12. Compressive strength of concrete with varying substitution ratios of dredged sediments C2

3.6 Tensile Strength

The results presented in Figure 13 indicate that the tensile strength of concrete is strongly influenced by the granulometry and cleanliness of the marine sediments. The granulometric analysis highlights a variable presence of fine particles (<2 μm), which negatively impact mechanical properties by increasing the specific surface area and disrupting the cement paste matrix. The sand equivalent test results confirm that C1 sediments, which are cleaner and contain fewer harmful fines, contribute to maintaining higher tensile strength. In contrast, C2 sediments, characterized by a higher impurity content, lead to a more pronounced reduction in mechanical performance.

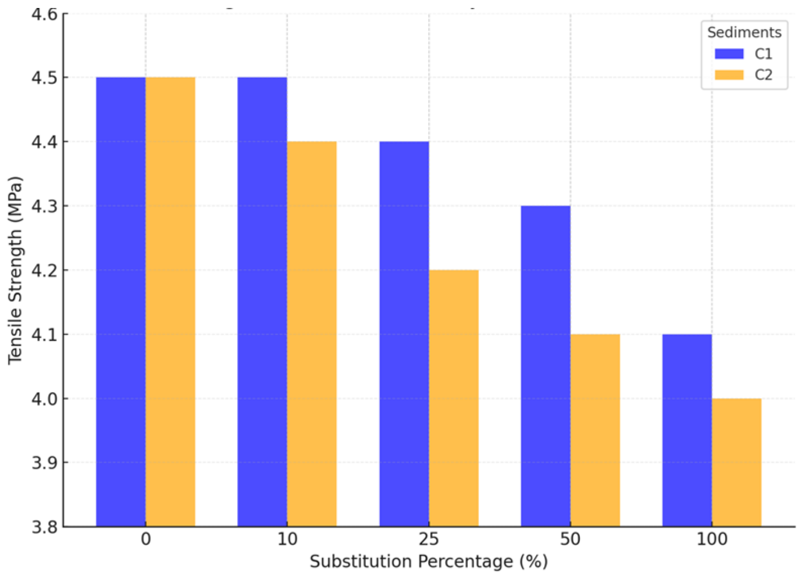

Fig. 13. Tensile strength of concrete at 28 days with varying substitution ratios of dredged sediments C1 and C2

4. Ecological Impact

Replacing dune sand with dredged sediments helps conserve natural sand resources, thereby protecting fragile ecosystems such as dunes and coastal environments. The compressive strength results (Figure 1) indicate that for substitution rates up to 25%, the concrete maintains adequate mechanical performance, making it suitable for non-structural applications.

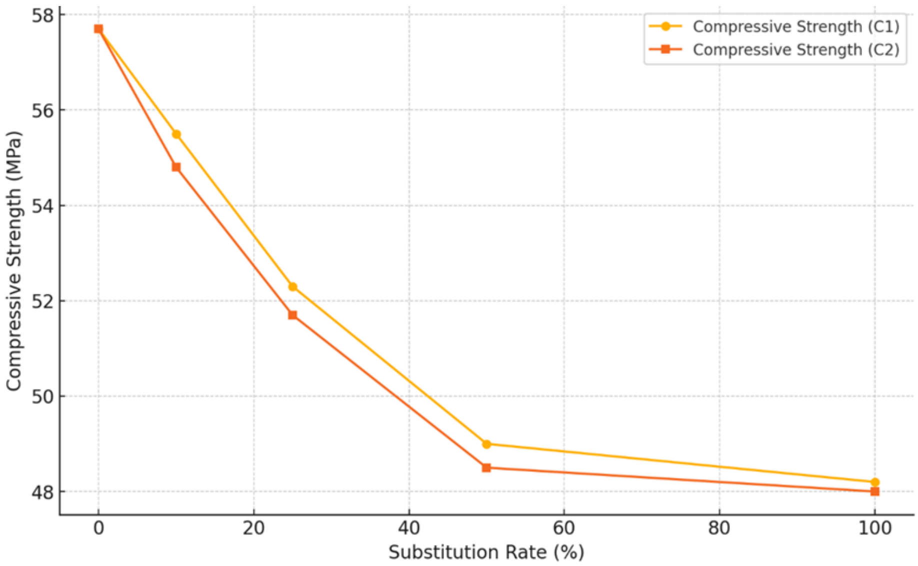

Fig. 14. The compressive strength of concrete at various substitution rates of dune sand with dredged sediments (C1 and C2 categories)

Figure 14 illustrates the relationship between the substitution rates of dune sand with dredged sediments (C1 and C2) and the compressive strength of concrete. The results show that as the substitution rate increases, the compressive strength gradually decreases. For C1 sediments, the 28-day compressive strength decreases from 57.7 MPa at 0% substitution to 48.2 MPa at 100% substitution. Similarly, for C2 sediments, the compressive strength decreases from 57.7 MPa to 48 MPa across the same substitution range. At lower substitution rates (10% and 25%), the impact on compressive strength is relatively minimal, with both C1 and C2 maintaining values above 50 MPa.

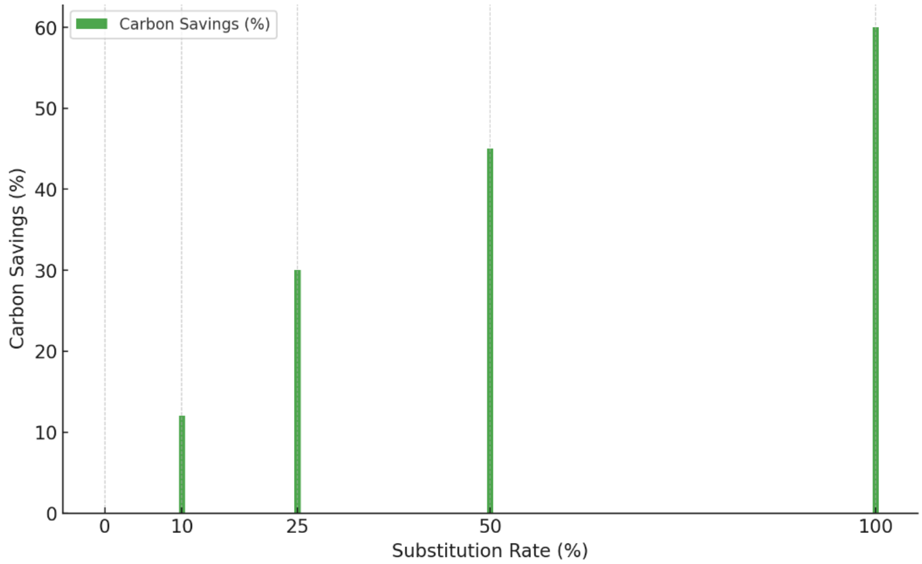

Fig. 15. Estimated percentage reduction in carbon emissions for different substitution rates of dune sand with dredged sediments

Figure 15 illustrates the carbon savings associated with replacing dune sand with dredged sediments in concrete production. The estimated savings increase progressively with the substitution rate, starting at 12% for a 10% substitution and reaching up to 60% for a complete replacement of dune sand.

5. Results and Discussion

The incorporation of dredged sediments from Jebha Port as a substitute for dune sand in concrete presents both advantages and challenges. This study highlights the impact of such substitution on the rheological and mechanical properties of concrete, emphasizing the need for optimization strategies to ensure material performance and sustainability. Recent studies have highlighted the use of marine dredged sediments as a sustainable alternative to dune sand in concrete [33]. The inclusion of such materials has been shown to reduce environmental impact and conserve natural resources [9].

One of the key observations in this study is the reduction in workability with increasing substitution rates. The slump test results indicate that workability remains acceptable at a 10% substitution level but declines significantly beyond 50%, particularly for C2 sediments. This decrease is primarily attributed to the higher presence of fine particles and active clay minerals, which increase water demand and disrupt the cohesion of the cementitious matrix [34]. To mitigate this effect, the use of a superplasticizer such as Tempo 25M or an alternative high-performance admixture is recommended [34].

Moreover, the cleanliness of sediments plays a crucial role in the overall workability of the mixture. Higher impurity content, particularly in C2 sediments, leads to a pronounced reduction in fluidity, which can be counteracted through a careful selection of additives and optimized mix designs. The incorporation of well-graded granular corrections may also improve the rheological behavior and limit excessive water demand, ensuring better cohesion and compaction of the mixture.

The compressive and tensile strengths of concrete decrease as the substitution percentage increases. At 28 days, the reference concrete exhibits a compressive strength of 57.7 MPa, while the fully substituted mix reaches 48.2 MPa for C1 sediments and 48 MPa for C2 sediments. At lower substitution levels (10%-25%), mechanical performance remains within acceptable limits, making these proportions suitable for non-structural applications [35]. However, at higher substitution rates, particularly at 50% and beyond, the presence of fines and impurities significantly affects the concrete's strength, underscoring the importance of controlling sediment quality [36].

Additionally, the results suggest that the presence of active clays in certain sediment samples, particularly in C2, contributes to a decline in adhesion and mechanical interlocking within the cementitious matrix. This phenomenon is confirmed by methylene blue test results, which indicate a higher adsorption capacity, signifying the presence of expansive clay minerals. To address this issue, supplementary treatments such as washing, thermal processing, or blending with coarser aggregates may be required to enhance the mechanical performance of the concrete. [37].

X-ray diffraction (XRD) analysis confirms that the sediments primarily consist of stable crystalline phases such as quartz and calcite, which contribute to their suitability as a construction material. However, the methylene blue test results reveal the presence of active clay minerals, especially in C2 sediments, which can weaken the adhesion within the cementitious matrix. This necessitates additional pre-treatment measures for sediments with high impurity levels before their incorporation into concrete [38].

Moreover, durability assessments indicate that moderate substitution rates do not significantly affect the long-term stability of the material. However, at higher incorporation levels, potential issues such as increased porosity and reduced resistance to aggressive environments must be considered. In particular, the susceptibility of certain samples to sulfate attack requires further study, and the addition of pozzolanic materials or supplementary cementitious binders may be necessary to enhance durability.

From an environmental perspective, replacing dune sand with dredged sediments offers a viable solution to reduce pressure on natural sand resources and mitigate the ecological consequences of uncontrolled sand extraction. Additionally, this approach significantly lowers the carbon footprint of concrete production by reducing transportation emissions and eliminating energy-intensive sand extraction processes. The estimated carbon savings range from 12% at a 10% substitution rate to approximately 60% at full replacement [39]. This approach aligns with circular economy principles, promoting the reuse of industrial by-products and reducing landfill disposal. Furthermore, the valorization of dredged sediments contributes to sustainable construction practices by integrating locally available materials, thus decreasing dependency on imported raw materials and fostering regional economic development [40].

For optimal use, it is recommended to limit substitution to moderate levels (≤25%) and incorporate chemical admixtures to counteract the negative effects of fines on workability. Furthermore, additional research should focus on the long-term durability of concrete containing dredged sediments, particularly under exposure to sulfate attack and freeze-thaw cycles. Investigating advanced processing techniques to improve sediment quality and assessing the economic feasibility of large-scale adoption will be crucial for integrating this sustainable practice into the construction industry. [41- 42]

Future studies should also explore the effects of sediment substitution on the thermal properties of concrete, particularly in applications requiring enhanced insulation performance. Additionally, life-cycle assessments and cost-benefit analyses will be essential to establish the broader economic and environmental viability of large-scale implementation.

6. Conclusion

This study highlights the promising potential of marine dredged sediments from Jebha Port as a sustainable alternative to traditional dune sand in B30 concrete. The results show that by replacing dune sand with marine dredged sediments up to 25%, the concrete retains an acceptable level of compressive strength, making it a good choice for non-structural applications where high strength is not as critical. However, increasing the sediment content beyond this level can reduce the concrete's strength, emphasizing the need for a careful balance when using these sediments. The addition of marine dredged sediments does affect the workability of the concrete mix. As the proportion of sediments increases, the mix becomes stiffer and harder to work with. However, this challenge can be addressed through adjustments in the mix design, such as incorporating admixtures or optimizing the water content. These changes could help maintain the workability of the concrete without losing the environmental benefits of using dredged sediments.

One of the strongest arguments for using marine dredged sediments is the positive environmental impact. Substituting dredged sediments for dune sand reduces the demand for sand mining, which is known to cause environmental harm such as habitat destruction, waterway disruption, and the depletion of natural sand resources. By using dredged sediments, we help conserve precious natural resources and reduce the environmental footprint of sand extraction. Although the short-term performance of concrete with marine dredged sediments looks promising, further research is necessary to assess its long-term durability. Tests on carbonation, shrinkage, and resistance to aggressive environments will be crucial in determining whether this concrete will hold up over time. These additional studies will provide valuable insight into the durability and long-term viability of using dredged sediments in construction.

In terms of sustainability, this research contributes to a more sustainable approach to construction by supporting the reuse of waste materials. By turning marine dredged sediments into a valuable resource, this study aligns with circular economy principles, reducing waste and minimizing the need for virgin materials. This innovative approach offers a practical solution to the challenges of natural sand depletion and environmental impact.

In conclusion, marine dredged sediments from Jebha Port offer a promising, sustainable alternative to traditional dune sand in concrete production. With some adjustments to the mix design and further research into long-term durability, these sediments can be effectively used in non-structural concrete applications. Not only does this approach help conserve natural sand resources, but it also sets the stage for more sustainable and eco-friendly practices in the construction industry. With continued research, marine dredged sediments could become a key player in the future of sustainable building materials.

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