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Sustainable valorization of marine dredged sediments from Jebha Port as a partial sand replacement in eco-friendly concrete

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ABSTRACT

The construction industry is increasingly seeking sustainable alternatives to natural sand due to its rapid depletion and environmental impact. Marine dredged sediments have emerged as a promising solution, offering both ecological and economic benefits. This study investigates the potential of dredged sediments from Jebha Port, northern Morocco, as a partial replacement for dune sand in concrete. Twelve sediment samples, collected from various locations within the port, were thoroughly analyzed to determine their physical, chemical, and mineralogical properties. These sediments, primarily composed of fine sands, were incorporated into concrete equivalent mortars (MBE) at substitution rates of 10%, 25%, 50%, and 100%. To optimize workability and mechanical performance, two advanced superplasticizers – Sika ViscoCrete-25 M Tempo and Sika ViscoCrete-1700 Tempo M – were tested. The findings reveal that replacing sand with dredged sediments influences the rheological and mechanical behavior of the mortar, with higher substitution levels presenting both challenges and opportunities. This research highlights a sustainable approach to reusing marine dredged sediments in the construction industry while ensuring material performance. The results confirm that at optimal substitution levels, these sediments can enhance the sustainability of construction materials without significantly compromising their mechanical properties.

Keywords: sustainable concrete, dredged sediments, sand replacement, mortar workability, mechanical performance, environmental construction materials, marine resource utilization.

INTRODUCTION

The dredging of marine sediments during land reclamation and port maintenance produces large volumes of material that require sustainable management to minimize environmental impact. A promising approach to addressing this challenge is the valorization of these sediments, particularly in the construction sector. Since sand constitutes a major fraction of dredged materials, its potential reuse in concrete production presents a viable and eco-friendly alternative. With the global depletion of high-quality construction sand becoming an increasing concern, the exploration of innovative and sustainable substitutes has become imperative to preserve natural resources and support the construction industry [1].

This study explores the feasibility of using marine dredged sediments from Jebha Port in northern Morocco as a sustainable alternative to conventional sand in concrete production. The selection of this site is driven by the substantial volume of sediment generated through dredging operations, which consists primarily of sand. When properly processed, these sediments have the potential to serve as a partial replacement for natural sand, contributing to sustainable construction practices and addressing the growing demand for eco-friendly building materials [2].

The experimental approach consists of formulating a reference concrete with conventional sand and evaluating its performance against concrete mixes incorporating different proportions of dredged sediments. This comparative analysis aims to assess the impact of sediment substitution on the material's rheological and mechanical properties [3]. Key performance indicators, such as workability, mechanical properties, and durability, are evaluated to determine the feasibility of using dredged sediments in concrete. Preliminary results suggest that the incorporation of water-reducing admixtures enhances performance, even at higher substitution levels, demonstrating the potential of these sediments as a sustainable alternative in construction [4].

The valorization of marine dredged sediments tackles two major challenges: sustainable sediment management and the preservation of natural sand resources. As sand is the second most consumed material globally after water, its depletion presents a growing concern for the construction industry. By incorporating dredged sediments into concrete, this study offers an innovative approach to reducing dependence on non-renewable resources, promoting a more sustainable and environmentally responsible construction sector [5].

Despite its potential, the use of dredged marine sediments in concrete remains underexplored in Morocco, with minimal research in this area. This paper seeks to bridge this gap by providing a detailed analysis of the feasibility and benefits of such an approach. Additionally, the valorization of dredged sediments offers coastal cities a dual benefit: improved navigability and sustainable material reuse, fostering a balance between development and environmental stewardship. This study not only addresses practical sediment management challenges but also proposes a path forward for sustainable urban development in coastal regions [6].

This study aligns with global and local sustainability goals, such as Morocco's Green Plan, which emphasizes innovative recycling and sustainable practices in infrastructure development.

MATERIALS AND METHODS

Dredging site

The dredged sediments used in this study were collected from Jebha Port, situated in northern Morocco, as depicted in Figure 1. Located in the Chefchaouen Province within the Tanger-Tétouan region, Jebha Port is approximately 162 km from Al Hoceima. The port is strategically positioned between the limestone cliffs of Pointe des Pêcheurs and the Misiaba River, close to the village of Jebha, with geographic coordinates of approximately 35°13'10" North and 4°40'45" West.

Sediment samples were collected from specific locations, with the exact coordinates of each drilling and sampling point clearly marked. Mechanical equipment was used to extract sediment samples from the designated sites following the dredging operation. These samples, weighing 900

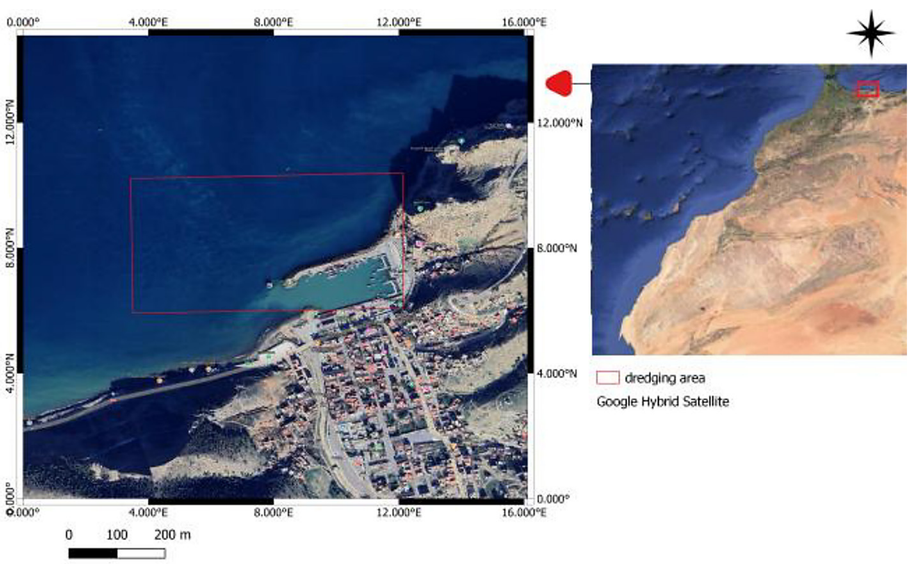

Figure 1. Map showing the location of the dredging site at Jebha Port

kg in total, were carefully stored in sealed plastic bags to preserve their integrity before being transported to the laboratory. Upon arrival, the samples were stored in a climate-controlled room at 20 °C to maintain optimal conditions for preservation until further analysis (Fig. 2) [7].

Physicochemical characterization of dredged sediments from Jebha Port

Variations in the specifications of dredged marine sediments can be attributed to several factors, including geological differences, local environmental conditions, and the specific port activities unique to each location. As such, the process of valorizing dredged sediments for use as construction materials must start with a thorough physicochemical characterization. This step is crucial for evaluating the sediment quality and gaining detailed insights into their physical, chemical, and mineralogical properties [8].

The data obtained from these analyses are essential for identifying the most appropriate valorization methods and tailoring treatment processes to optimize the use of dredged sediments in construction applications. This information helps ensure that the sediments meet the necessary requirements for effective incorporation into construction materials (Fig. 3).

The physicochemical analysis was conducted on 12 sediment samples collected from each of

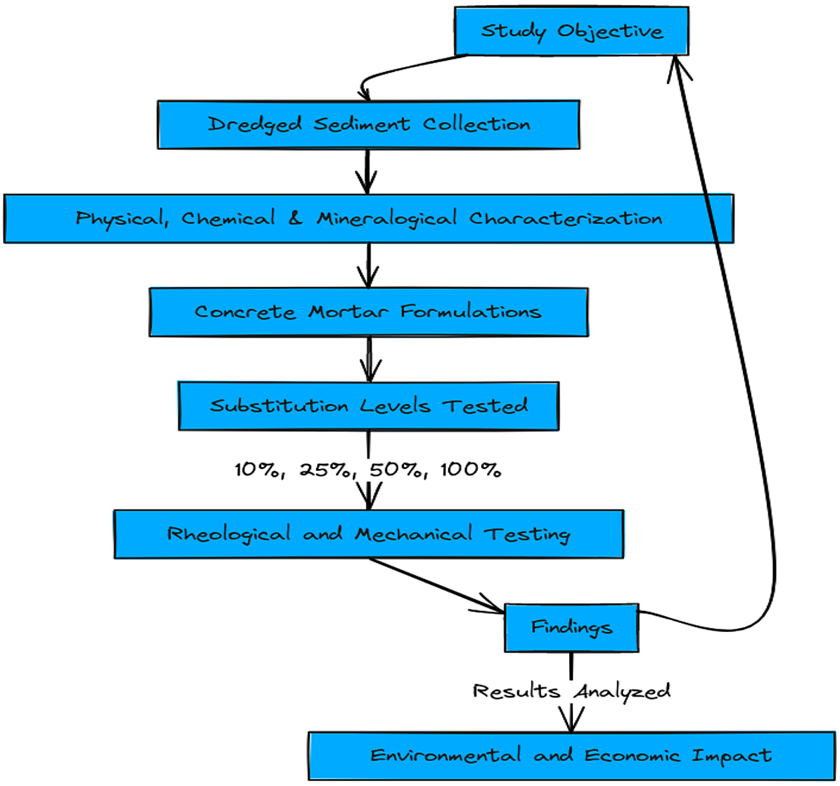

Figure 2. The process of dredged sediment utilization in mortar production

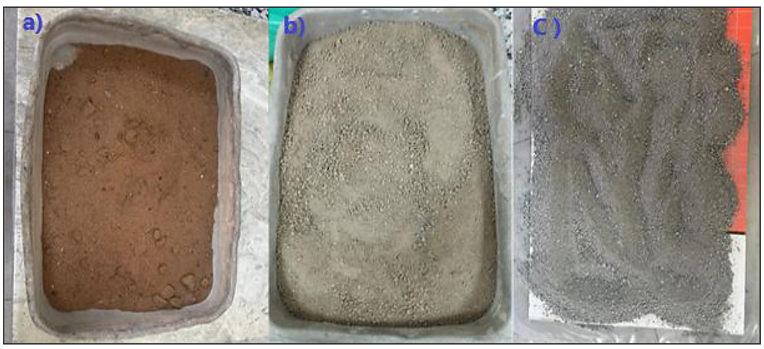

Figure 3. Dune sand (a), dredged sediments (b), and crushed sand (c) used for the formulations

the dredging locations, in compliance with Morocco's relevant standards. Table 1 outlines the parameters measured, the methods employed, and the corresponding standards [9–17]. The tests include assessments for granulometry, density, cleanliness, carbonate content, organic matter content, loss on ignition, elemental composition, mineral identification, and pH.

Granulometric analysis was performed using two methods: dry sieving after washing and sedimentation with a deflocculant. The dry sieving method separates particles by size using standard sieves, while the sedimentation method employs a deflocculant to disperse the sediment particles, allowing them to settle in a column. This process facilitates the determination of the particle size distribution (Fig. 4) [18].

The dune sand represents natural deposits, the dredged sediments are marine-derived materials, and the crushed sand is an industrial by-product, each tested to highlight their unique contributions to the mortar properties.

The chemical composition of the sediments was analyzed using X-ray fluorescence (XRF), a technique that offers detailed insights into the elemental makeup of the samples. This method enables accurate determination of the concentrations of key elements such as calcium, iron, magnesium, and others. Additionally, the pH of the sediments was measured with a calibrated pH meter, following standard protocols [19].

The organic content was determined by calcining the sediment fractions at 450–500 °C for 3 hours. The weight loss observed during this process directly corresponds to the amount of organic material present in the sediments. Similarly, the carbonate content, particularly $CaCO_3$, was assessed through titration, offering valuable

Table 1. Physicochemical characterization parameters for dredged sediments from Jebha Port – these standards were chosen to ensure that the analysis aligns with local construction practices while also adhering to international best practices for sediment characterization

Parameter	Method and principle	Standard
Granulometry	Dry sieving after washing	NM 00.8.082 [9]
	Granulometric analysis by sedimentation with deflocculant	NM 00.8.083 [10]
Density	Determination of sediment density using pycnometer	NF P 94-014: 1996 [11]
Cleanliness (fines content)	Measurement of sand equivalent with 10% fines: measures cleanliness of sand with fractions	NM 10.1.732 [12]
	Methylene blue test	NF P 94-026 [13]
Carbonate content	Determination of $CaCO_3$ content (%) using titration method	NF P 94-048: 1996 [14]
Organic matter content	Determination of organic matter content (%): calcination of 0–2 mm fraction at 450–500 °C for 3 hours	NF P 94-055: 1993 [15]
Loss on Ignition	Determination of loss on ignition at 1000 °C (% LOI)	NM 10.1.005: 2008 [16]
Elemental composition	Chemical analysis by X-ray fluorescence spectrometry (%)	NM 10.1.005: 2008[16]
Mineral identification	X-ray diffraction (XRD)	-
pH	pH determination using pH meter	NF ISO 10390: 2005 [17]

Figure 4. Samples dried at 105 °C (a), and sieved through 4 mm mesh sieves (b)

insights into the chemical properties of the sediments and their suitability for use in construction applications [20].

The loss on ignition (LOI) test was conducted at 1000 °C to determine the amount of volatile substances present in the sediments. This test is particularly useful in assessing the presence of organic materials, carbonates, and other volatile compounds that may influence the sediment's handling and final use [21] (Fig. 5 and 6).

RESULTS AND DISCUSSION

The dredged sediments from Jebha Port have been extensively analyzed to assess their suitability as a partial replacement for natural sand in concrete equivalent mortars (CEMs). The results of the comprehensive physicochemical tests offer valuable insights into the material's properties and its potential for use in construction applications.

Granulometric and physical properties

The granulometric and physical properties of the 12 dredged sediment samples from Jebha Port are presented in Table 2. These samples exhibited varying particle size distributions, with a significant portion (ranging from 45% to 87% of the total mass) falling between 80 µm and 2 mm in size. The fineness modulus values ranged from 0.39 to 2.25, indicating that the sediments were predominantly fine to medium sand.

Chemical and mineralogical composition

The chemical and mineralogical composition of the sediments was evaluated using X-ray fluorescence (XRF) and X-ray diffraction (XRD) analysis (Tables 3 and 4). The sediments primarily consist of silicon oxide (SiO_2), with values ranging from 66.46% to 79.01%, followed by smaller amounts of aluminum oxide (Al_2O_3), iron oxide

Figure 5. Mixing of concrete in the mixing container (a), filled cylindrical mold for slump flow test (b), spread of concrete after the slump flow test (c)

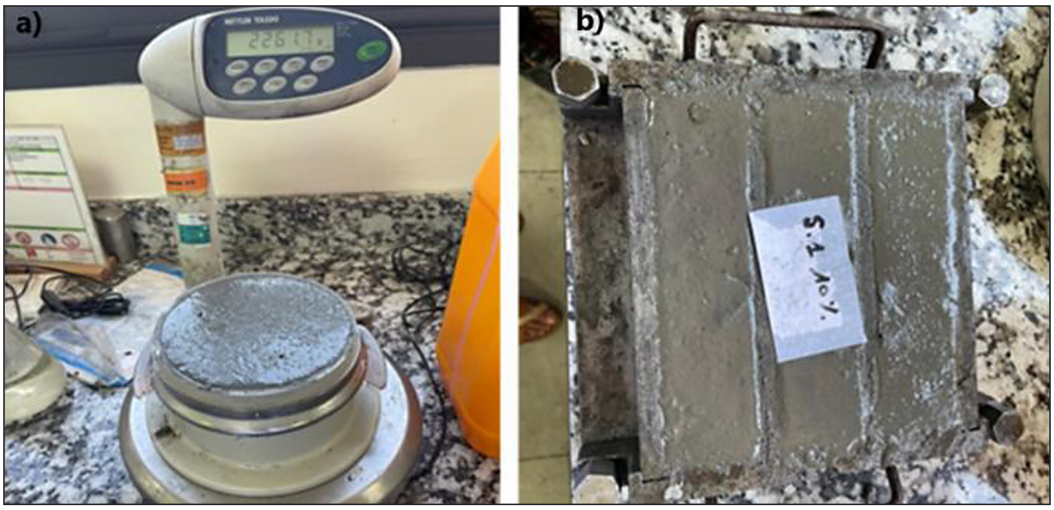

Figure 6. Density measurement (a), and filling of the mini cone using the MBE (b)

Table 2. Granulometric and physical properties of dredged sediments

Parameter	Results	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Granulometry (%)	D max (mm)	12.5	25	20	2.5	31.5	12.5	25	12.5	31.5	1	20	2
Ø > 20 mm		0	3	0	0	6	0	2	0	3	0	0	0
Ø > 2 mm		11	7	8	1	14	2	2	10	18	0	10	0
80 µm < Ø < 2 mm		71	65	73	69	69	65	45	78	59	56	69	87
Ø < 80 µm		18	28	19	30	17	33	53	12	23	44	21	13
20 µm < Ø < 80 µm		9	17	11	18	9	18	33	7	14	27	11	8
2 µm < Ø < 20 µm		7	9	6	9	6	11	15	4	7	13	7	4
Ø < 2 µm		2	2	2	3	2	4	5	1	2	4	3	1
Fineness modulus		1.76	1.42	1.81	0.66	2.13	1.74	0.39	2.25	1.71	0.55	1.96	1.64

Table 3. Chemical and mineralogical properties of dredged sediments

Parameter	Results	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Density (g/cm³)	Average density												
Cleanliness (Fines content)	Sand equivalent	46	42	45	37	43	44	24	42	41	36	40	46
Methylene blue test value	Methylene blue test value (g/100g)	2.18	2.23	2.28	2.93	1.72	2.17	3.40	1.75	2.38	2.97	1.76	2.27
Organic matter Content (%)	Organic material percentage	0	0	1	1	1	0	1	1	0	1	1	1
Carbonate content (% $CaCO_3$)	Calcium carbonate content	6.26	8.27	8.26	9.38	9.07	5.84	7.62	8.00	9.38	12.90	8.80	7.13
Carbon Content (%)	Carbon content	0.82	0.79	0.83	0.97	0.90	0.49	0.77	0.61	0.87	1.25	0.85	0.74
Loss on ignition at 1000 °C (%)	Loss on ignition at 1000 °C	6.29	7.83	8.26	9.19	8.34	5.50	7.86	8.18	8.68	10.26	8.11	7.58
pH	pH meter	9.16	8.91	8.80	8.80	8.78	8.89	8.63	8.60	8.79	8.60	8.80	8.73

Table 4. X-ray fluorescence (XRF) analysis of dredged sediments

Parameter	Results	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Silicon oxide (SiO_2)	%	74.52	70.59	68.49	66.94	67.84	79.01	70.00	71.56	67.35	66.46	70.51	71.50
Iron oxide (Fe_2O_3)	%	3.95	4.55	4.83	4.01	3.79	3.36	3.81	3.59	5.10	3.81	4.33	4.19
Aluminum oxide (Al_2O_3)	%	6.22	6.62	7.51	7.78	7.81	5.06	8.00	6.10	7.67	6.26	6.55	6.60
Calcium oxide (CaO)	%	4.53	6.32	6.43	7.12	7.20	3.84	5.48	5.88	6.66	8.81	6.56	5.94
Magnesium Oxide (MgO)	%	1.26	1.32	1.41	1.87	1.89	0.98	1.78	1.57	1.53	1.74	1.29	1.43
Phosphorus oxide (P_2O_5)	%	0.06	0.05	0.06	0.06	0.09	0.04	0.07	0.06	0.06	0.06	0.05	0.06
Titanium oxide (TiO_2)	%	0.35	0.36	0.39	0.35	0.33	0.31	0.37	0.35	0.39	0.34	0.36	0.41
Sodium oxide (Na_2O)	%	1.42	0.86	0.94	1.16	1.38	0.71	1.28	1.43	0.91	0.92	0.83	0.94
Potassium oxide (K_2O)	%	1.24	1.37	1.54	1.39	1.19	1.06	1.30	1.14	1.61	1.21	1.29	1.25

(Fe_2O_3), and calcium oxide (CaO). This high quartz content is consistent with their potential as a sand substitute, as it indicates low reactivity and stability when used in construction.

The methylene blue test values ranged from 1.72 to 3.40 g/100 g, suggesting the presence of finer particles that could impact the water demand in the mixture. The pH values of the sediments were found to be alkaline, ranging from 8.60 to 9.16.

Rheological and mechanical properties

The rheological properties of the mortar were evaluated by measuring workability using the spread test, while the mechanical properties were assessed through compressive and tensile strength tests.

The results showed that up to a 50% substitution of sand with dredged sediments, the workability of the mortar was maintained at acceptable levels when Sika ViscoCrete®-25 M Tempo, a water-reducing superplasticizer, was used. The addition of the superplasticizer helped mitigate the increased water demand associated with higher fines content in the dredged sediments.

At 100% substitution the workability significantly reduced, which is attributed to the high proportion of fine particles (< 80 µm), which absorb more water and increase the viscosity of the mixture. This can lead to difficulties in mixing and placing the mortar, particularly in large-scale applications.

Compressive strength

As shown in Figure 7, the compressive strength of CEMs progressively decreased as the substitution ratio of dredged sediments increased. For substitution levels up to 50%, the strength values remained within the acceptable range for non-structural applications. However, at 100% substitution, there was a significant decline in compressive strength, indicating that the bonding strength of the dredged sediments was lower than that of natural dune sand. This reduction in strength can be attributed to the lower cementitious content of the dredged sediments, which contain fewer reactive minerals compared to natural sand. While 100% substitution may not be suitable for structural applications, the material could still be viable for non-load-bearing constructions or when combined with other additives to improve strength.

Figure 8 shows the tensile strength results, which mirrored the trend observed for compressive strength. The tensile strength also declined with higher substitution ratios, reflecting the same challenges related to the lower bonding strength of the dredged sediments.

Figure 7 illustrates the effect of substituting natural sand with dredged sediments on the compressive strength of CEMs. As the substitution ratio increases, a clear decline in compressive strength is observed. Up to a substitution level of 50%, the compressive strength values remain within an acceptable range for non-structural applications, indicating that the sediments provide sufficient cohesion and bonding for such uses. However, at 100% substitution, there is a significant drop in compressive strength. This reduction can be attributed to the lower content of reactive minerals and the higher proportion of fine particles in the dredged sediments, which compromise the bonding capacity and compactness

Figure 7. Evaluation of concrete equivalent mortars (CEMs); shrinkage-swelling and compressive strength testing

of the material. These results suggest that while dredged sediments can be effectively used at moderate substitution levels, higher ratios may require further optimization, such as the addition of advanced superplasticizers or other admixtures to enhance performance.

The graph demonstrates a decrease in shrinkage over time for all three samples, with noticeable variations in their performance. At the 1-day mark, sample S1 exhibits the highest shrinkage value of 0.730 mm, followed by sample S2 at 0.650 mm. Sample S, a combination of S1 and SC in a 50/50 ratio, shows the lowest shrinkage at 0.580 mm. This suggests that the combined sample is more resistant to early shrinkage compared to the individual components.

At 7 days, the shrinkage values for all samples show a significant decrease. Sample S1 records a shrinkage of 0.593 mm, while S2 decreases to 0.513 mm. The combined sample S continues to exhibit the lowest shrinkage value of 0.445 mm, maintaining its superior performance. This trend suggests that the combined material stabilizes more quickly, likely due to its balanced composition, which helps reduce internal stresses during the drying process.

By 28 days, the shrinkage values for all samples appear to stabilize, with no significant changes observed compared to the 7-day measurements. Sample S1 maintains a shrinkage value of 0.593 mm, S2 remains at 0.513 mm, and the combined sample S continues to show the lowest shrinkage at 0.445 mm. This stability over time reinforces the conclusion that combining materials in a 50/50 ratio enhances long-term dimensional stability (Fig. 9).

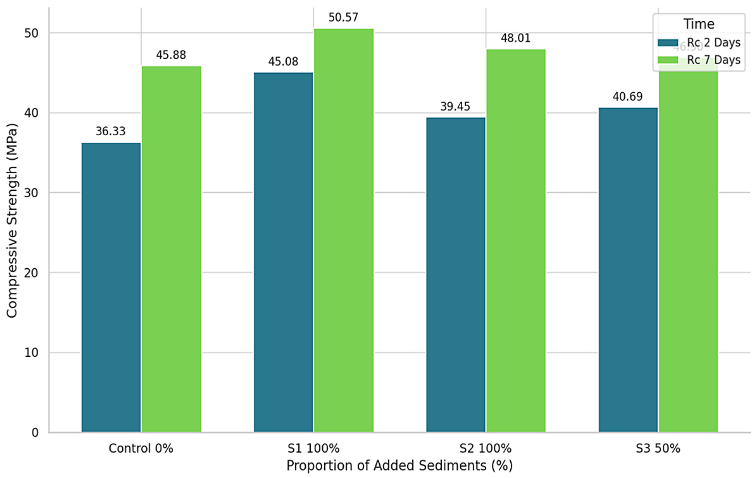

Figure 8. Compressive strength of concrete equivalent mortars (CEMs) with varying substitution ratios of dredged sediments

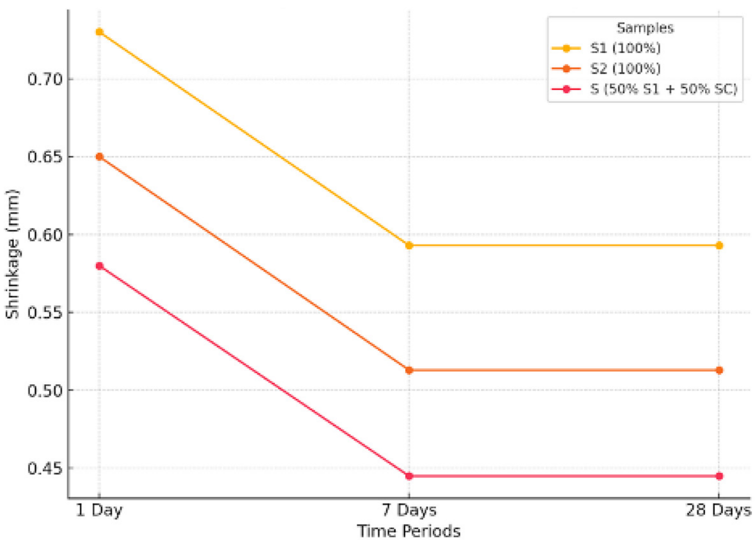

Figure 9. Shrinkage variation over time (1 day, 7 days, and 28 days) for three different samples

Figure 10 illustrates the tensile strength of CEMs with varying substitution ratios of dredged sediments. The trend follows that of compressive strength, with tensile strength decreasing as the proportion of dredged sediments increases. At substitution ratios up to 50%, the tensile strength remains within a satisfactory range for certain construction applications, indicating that the material retains sufficient cohesion to resist tensile stresses. However, beyond this level, the tensile strength declines sharply, reflecting the limited bonding capability of the finer particles in the dredged sediments

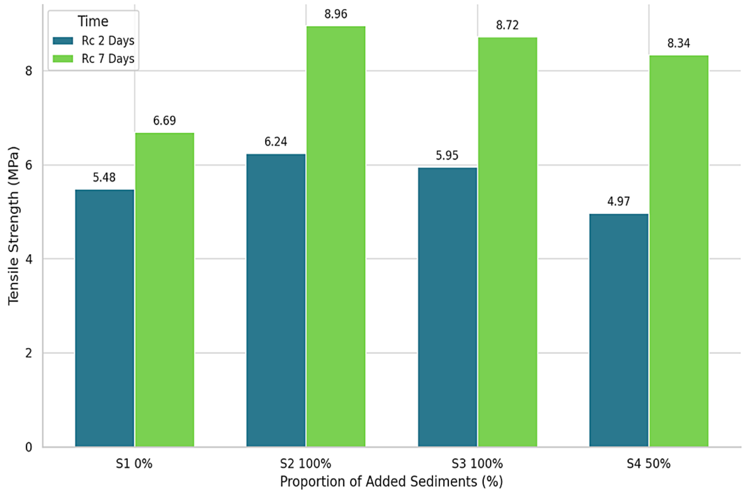

Figure 10. Tensile strength of CEMs with varying substitution ratios of dredged sediments

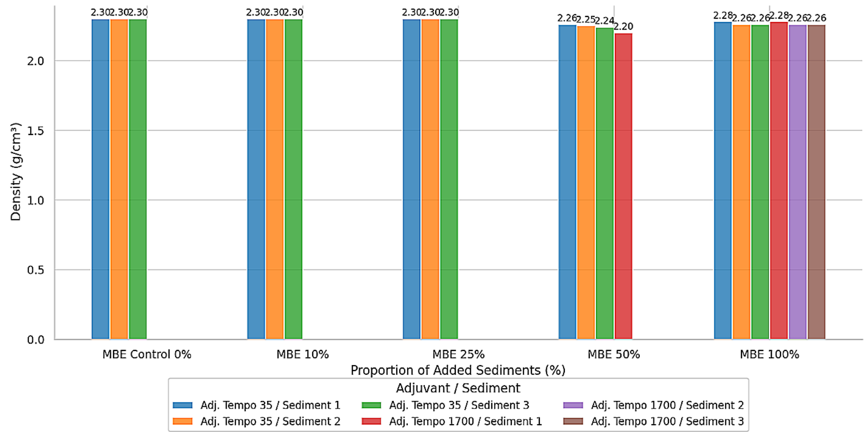

Figure 11. Effect of substitution ratios on the slump flow of mortars

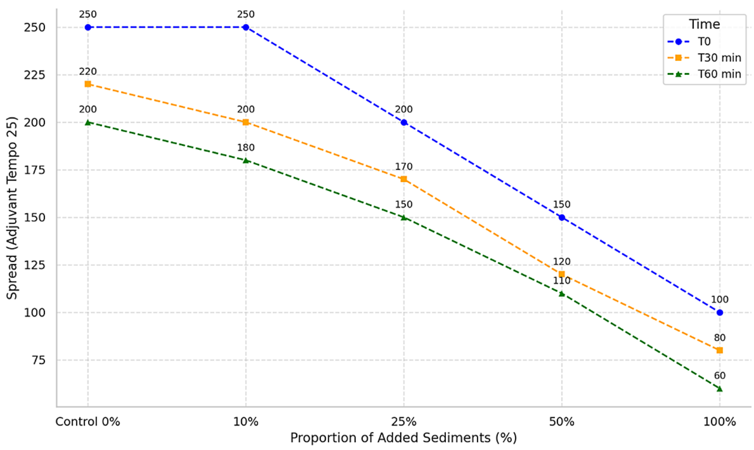

Figure 12. Capillary water absorption of mortars with dredged sediment substitution

The slump flow results reveal the effect of increasing substitution ratios of natural sand with dredged sediments on mortar workability. At lower substitution levels (10% to 50%), the mortar retains adequate flowability due to the inclusion of superplasticizers, indicating that the sediment particles are well dispersed within the mix. At 100% substitution, the slump flow decreases significantly, reflecting reduced workability. This decline is attributed to the higher fines content in dredged sediments, which increases water demand and mixture viscosity (Fig. 11).

This Figure 12 demonstrates the capillary water absorption behavior of mortars with increasing substitution ratios of dredged sediments. Up to a substitution level of 50%, the water absorption is comparable to that of control mortars, suggesting minimal impact on the pore structure. However, at 100% substitution, the absorption rate increases significantly, indicating higher porosity. This is likely due to the finer sediment particles creating more capillary pathways, which enhances water retention within the material.

Porosity measurements show a gradual increase as the substitution ratio rises. Up to 50%, the increase in porosity is minimal, remaining within acceptable standards for non-structural applications. However, at 100% substitution, porosity increases significantly, leading to a reduction in density that may negatively impact the mechanical performance of the material (Fig. 13).

This Figure 14 evaluates the resistance of mortars to chemical degradation from sulfates. Mortars with substitution levels up to 50% demonstrate similar durability to the control mix, indicating adequate resistance to environmental degradation. At 100% substitution, there is a noticeable reduction in resistance, likely due to the

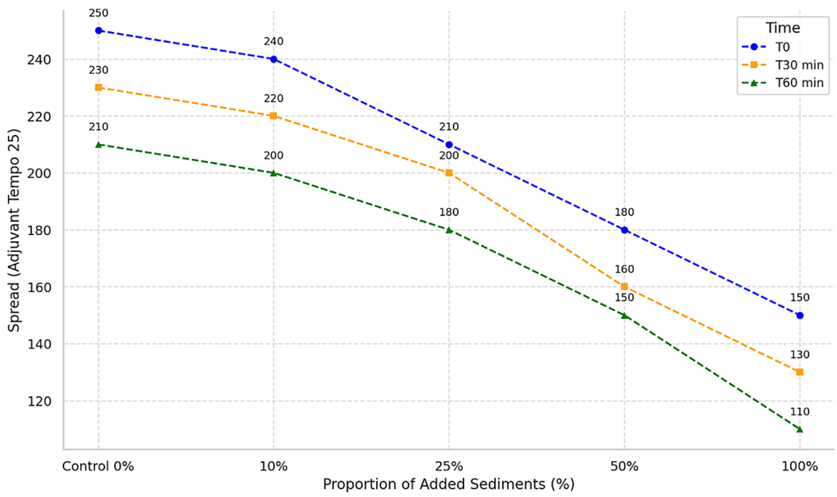

Figure 13. Porosity variation in mortars with different substitution ratios

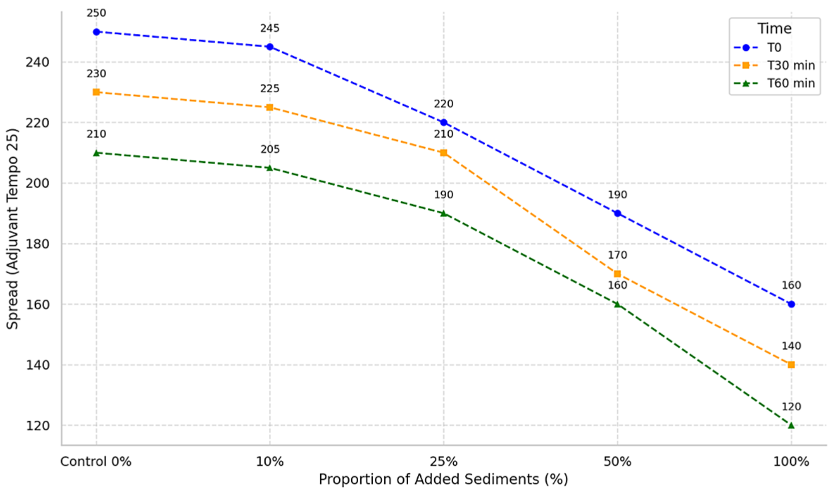

Figure 14. Durability of mortars under sulfate attack at varying substitution ratios

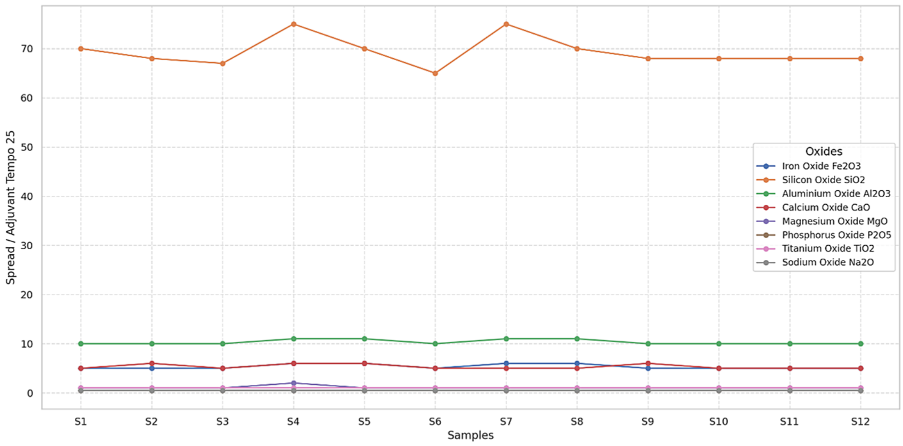

Figure 15. Economic and environmental benefits of using dredged sediments in construction

increased porosity and reduced cohesiveness of the sediment-based mixtures.

This Figure 15 highlights the economic and environmental advantages of using dredged sediments as a sand substitute. Economically, the approach reduces costs associated with natural sand procurement and sediment disposal. Environmentally, it alleviates pressure on sand resources and minimizes waste disposal challenges, contributing to sustainable construction practices. The figure underscores the potential for local sourcing and reduced carbon footprint in projects near dredging sites, demonstrating the dual benefit of cost savings and environmental impact reduction.

DISCUSSION

In this study, we explore the potential of using dredged sediments from Jebha Port as a partial substitute for natural sand in concrete equivalent mortars (CEMs). The physicochemical characterization of these sediments provided valuable insights into their composition, highlighting their high quartz content (66.46–79.01% SiO_2) and low organic matter content (< 1%), which suggest they are suitable for construction applications. However, the substitution of dredged sediments in concrete revealed both challenges and opportunities, particularly as the substitution levels increased. These findings point to the need for careful consideration of optimal substitution rates to balance performance and material properties effectively.

The results of this study show that dredged sediments from Jebha Port can effectively replace natural sand in concrete equivalent mortars, with substitution levels of up to 50% maintaining satisfactory workability and mechanical performance. However, higher substitution rates lead to challenges such as decreased strength and workability. To address these issues and optimize mixture properties, the incorporation of high-performance superplasticizers is required. These findings highlight the potential of dredged sediments as a sustainable alternative to natural sand, although further refinement of mixture formulations may be necessary for higher substitution levels.

The chemical and physical characteristics of the dredged sediments, including their high quartz content and low organic matter, make them a viable alternative to natural sand for non-structural applications in concrete production. Additionally, the valorization of these sediments addresses both environmental and economic challenges, contributing to sustainable construction practices, The potential for chemical leaching from the dredged marine sediments used in concrete should be considered. Leaching of harmful substances, such as heavy metals, could be a concern, especially if the sediments contain contaminants from port activities. To assess this risk, future studies could incorporate leachate tests to measure the release of any toxic compounds into the environment under varying environmental conditions. This would provide crucial insights into the environmental safety of using marine dredged sediments in construction applications.

The spread measurements showed that substitution levels up to 50% maintained acceptable workability with Sika ViscoCrete®-25 M Tempo. At higher substitution levels (100%), a significant reduction in workability was observed. This was attributed to the high fines content (< 80 μm), which increases the water demand of the mixture.

The introduction of a more powerful superplasticizer, Sika ViscoCrete®-1700 Tempo M, effectively mitigated these challenges, restoring the workability even at 100% substitution.

The compressive and tensile strength results indicate a gradual decline with increasing substitution ratios. This can be linked to the lower bonding strength of the dredged sediments compared to natural dune sand. However, substitution levels up to 50% still achieved acceptable strength values for standard construction applications. The reduced tensile performance at 100% substitution highlights a key limitation for structural applications, suggesting that while dredged sediments can be used as a partial substitute, additional treatment or modification may be required to improve their tensile properties for wider use.

At 100% substitution, while strength values dropped more significantly, the material's performance remained within tolerable limits for non-structural applications. These findings highlight the importance of optimizing the mix design to maintain workability when using higher substitution levels.

The reuse of dredged sediments presents a dual benefit: reducing the environmental burden of sediment disposal and conserving natural sand resources, which are increasingly scarce. This aligns with sustainable development goals (SDG 12) on responsible consumption and production. The results suggest that while moderate substitution levels do not compromise water resistance, higher levels may require treatment to improve durability. This highlights the need for additional compaction or the use of supplementary materials, such as fly ash or silica fume, to reduce porosity in high-substitution mixtures.

The results of this study demonstrate that marine dredged sediments from Jebha Port can partially replace natural sand in mortars, offering both environmental and economic benefits. Similar findings were reported by Wang et al. (2022) [22], who observed that substitution levels up to 50% maintained mechanical performance within acceptable limits for non-structural applications. However, at higher substitution ratios, challenges such as reduced compressive and tensile strength were noted, mirroring the findings of Zhao et al. (2019) [23].

In terms of workability, the decrease in slump flow at higher substitution ratios aligns with the observations of Ye et al. (2024) [24], who attributed this trend to the higher fines content and water absorption of dredged sediments. The use of superplasticizers, as highlighted in Heidari et al. (2024), effectively mitigated these issues, ensuring acceptable rheological properties up to 50% substitution.

The study also revealed an increase in porosity and water absorption with higher substitution levels, Increased porosity due to the substitution of sand with marine dredged sediments can lead to a higher absorption of water, potentially weakening the material's structural integrity. This can result in a reduction in compressive strength, as observed in the results at higher substitution levels. Moreover, excessive porosity may make the material more susceptible to environmental degradation, such as sulfate attack, which could undermine the long-term durability of concrete, particularly in regions with aggressive environmental conditions which is consistent with Hayek et al. (2023) [5]. These authors emphasized the need for supplementary materials, such as silica fume, to reduce porosity and improve durability in sediment-based concretes.

Regarding durability under sulfate attack, mortars with substitution ratios up to 50% exhibited comparable resistance to control mixes, a finding corroborated by Lv et al. (2020) [25]. However, at 100% substitution, reduced resistance was observed, highlighting the need for pre-treatment of sediments or the addition of pozzolanic materials to enhance chemical stability.

From an economic perspective, the reduction in costs associated with sediment disposal and natural sand procurement aligns with the findings of Norén et al. (2022) [26]. Furthermore, the environmental benefits of reducing sand extraction were emphasized in studies by Souileh et al. (2024) [27], who demonstrated a significant reduction in carbon footprint through local sourcing of alternative materials.

From an environmental perspective, the valorization of dredged sediments from Jebha Port offers a sustainable solution to the challenge of sediment disposal. These sediments, which are typically considered waste and require expensive disposal methods, can now be repurposed as valuable construction materials. This not only minimizes environmental impact but also contributes to the conservation of natural sand resources, which are increasingly in demand and facing depletion globally [28].

Economically, utilizing dredged sediments as a substitute for sand can reduce the cost of sand procurement, particularly in coastal regions where sediment disposal fees are high. This approach also creates opportunities for the construction industry to use locally sourced materials, thereby lowering transportation costs and reducing the carbon emissions associated with importing sand [29].

CONCLUSIONS

This study demonstrates the significant potential of dredged sediments from Jebha Port as a partial replacement for natural sand in concrete production. The results show that substitution levels up to 50% maintain acceptable mechanical and rheological performance, making these sediments suitable for non-structural and certain structural applications. However, at substitution ratios exceeding 50%, challenges such as reduced compressive strength and compromised workability emerge. These issues can be mitigated through the use of high-performance superplasticizers, such as Sika ViscoCrete®-1700 Tempo M, to improve the workability of the mixtures.

Beyond addressing the depletion of natural sand resources, this valorization approach offers a sustainable solution to sediment management by repurposing waste materials, which otherwise require costly disposal methods. This strategy not only reduces environmental impact but also contributes to the conservation of non-renewable resources, supporting broader sustainability objectives.

For future development, additional research is necessary to evaluate the long-term durability of concrete produced with dredged sediments, investigate the scalability of this process for industrial applications, and explore pre-treatment methods to enhance the properties of dredged sediments. Such efforts would further optimize the use of these materials, offering a viable pathway for sustainable construction practices.

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