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Geotechnical Improvement of Dredged Marine Soil Using Blended Cement and Rice Husk Ash for Subgrade: Strength and Mix Evaluation

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Abstract

Dredged Marine Soil (DMS) is a waste material produced from dredging activities in marine waters. Although recent studies have shown its potential use in construction, untreated DMS is generally unsuitable for direct application, especially in road construction. Therefore, DMS must be mixed with stabilizers, such as cementitious or pozzolanic materials, to enhance its strength, durability, and load-bearing capacity prior to use in road construction The characteristics of DMS are high moisture content, low strength, and high compressibility. This study aims to evaluate the effectiveness of DMS stabilization using a mixture of Ordinary Portland Cement (OPC) and Rice Husk Ash (RHA) for use as a subgrade layer in road construction. To identify DMS characteristics and chemical composition of RHA, laboratory tests such as hydrometer, Atterberg limit, compaction characteristics, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) and Scanning Electron Microscopy (SEM). The mixing ratio of cement (4%, 6%, and 8%) and RHA (5% and 10%) were tested at curing periods of 7, 14, and 28 days. The results showed that untreated DMS had low strength and did not meet the requirements of the JKR (2020) specification for subgrade applications. The addition of cement and RHA was proven to significantly improve the mechanical performance of DMS soil, where the strength increased in line with the curing period. The optimum mixture was identified at a ratio of 5% RHA and 6% cement, which met the minimum strength requirements of road subgrade with more efficient cement usage. SEM analysis confirmed the presence of amorphous silica and the formation of binding products in RHA contributed to the increase in soil strength. Overall, this study proved that the use of cement and RHA mixture is an effective and sustainable method to improve the engineering properties of marine dredged soil for road construction applications.

1. Introduction

Dredged Marine Soil (DMS) produced through dredging operations in port and waterway routes carried out to ensure the waterway level through dredging operations, which has been considered a waste but has good potential due to its high availability, especially in coastal regions like Malaysia (1). This DMS also lacks good geotechnical strength in terms of high moisture content, low shear strength, and poor bearing capacity; therefore, it cannot be applied in the construction of embankments, roads, and land reclamations and fills (2). In Malaysia, the locations where DMS can be found include Lumut, Melaka, Kuala Perlis, and Endau Rompin.

Various soil stabilization methods have been employed to overcome these problems, with cement being commonly used as a stabilizer. Nonetheless, there are limitations in the efficiency of cement and its high carbon footprint is largely considered environmentally unfriendly (3). Another sustainable option is to utilize Rice Husk Ash (RHA), an agricultural waste that is rich in silica with the potential of enhancing strength and durability of soils when blended with cementitious material (4). Research by (5) demonstrated that when cement is mixed with RHA the strength and load bearing capacity of DMS can be substantially improved and hence could be used as a construction material for subgrade. This paper explores the possibility of utilizing a cement and RHA mixture for DMS stabilization, which offers utilization of waste material and sustainable construction practices.

2. Materials and Method

2.1 Materials used

This research investigates the stabilisation of dredged marine soil (DMS) using Ordinary Portland Cement (OPC) and Rice Husk Ash (RHA). Dredged marine soil is a waste material generated from dredging activities and is generally unsuitable for geotechnical applications due to its high plasticity and low strength.

OPC is commonly used to improve soil strength. However, its production has significant environmental impacts, particularly high carbon emissions. As a result, there is increasing interest in identifying more sustainable alternatives. Rice Husk Ash (RHA), an agricultural by-product from rice milling, is a potential pozzolanic material that can partially replace OPC and reduce the environmental impact of soil stabilisation.

Therefore, the objective of this study is to evaluate the effectiveness of using RHA as an economical and eco-friendly industrial by-product for the stabilisation of dredged marine soil.

(a) (b) (c)

Fig 1 (a) *Dredged Marine Soil (DMS) Endau* (b) *Ordinary Portland Cement (OPC)* (c) *Rice Husk Ash (RHA)*

2.2 Method

Initially, the DMS samples were stored in containers and dried at 105°C for 24 hours to remove excess moisture. After drying, the soil was sieved to separate particles based on their size. The sieve sizes used were 0.425 mm for Atterberg tests, 0.212 mm for specific gravity (SG), and 0.475 mm for California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests and 0.075mm for hydrometer test. Ordinary Portland Cement (OPC) used in this study was sourced from the laboratory's concrete materials, ensuring its suitability for stabilisation purposes. Rice Husk Ash (RHA), a by-product from the rice milling industry, was used as a stabilizing agent. Figure 2 shows the methodology of this study.

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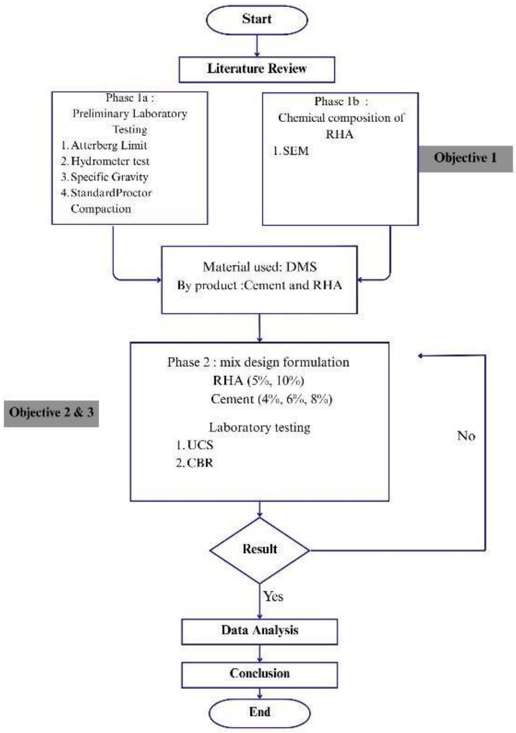

Fig 2 *Flowchart of experiment*

2.3 Laboratory Testing Programme

In this study, divide by 2 phases, which is preliminary laboratory testing such as Atterberg limit, hydrometer, specific gravity, standard proctor compaction and chemical composition of RHA were tested for phase1.Then, laboratory testing for mix evaluation such as Unconfined Compressive Strength (UCS) and California Bearing ratio (CBR) were determined in phases 2.

2.3.1 Atterberg Limit Test

The plasticity characteristics of fine-grained soils were evaluated using the Atterberg Limits test. The liquid limit (LL) represents the moisture content at which soil changes from a plastic to a liquid state, while the plastic limit (PL) is the moisture content at which soil changes from a plastic to a solid state. The difference between these two limits is known as the Plasticity Index (PI), which indicates the range of moisture content over which the soil exhibits plastic behaviors. These parameters are commonly used for soil classification and to assess soil suitability for engineering applications in accordance with British Standard–based methods. (6)

Fig 3 *Equipment of Atterberg limit test*

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2.3.2 Specific Gravity

The specific gravity test measures the ratio of the unit mass of soil particles to the unit mass of water, essential for determining weight volume relationships in geotechnical applications. Three soil samples, each weighing about 7 g, were tested after passing through a 0.212 mm sieve to ensure uniformity. The samples were placed in a vacuum desiccator for one hour to remove any air, preventing an underestimation of the specific gravity. The test provides important data for soil analysis in geotechnical work

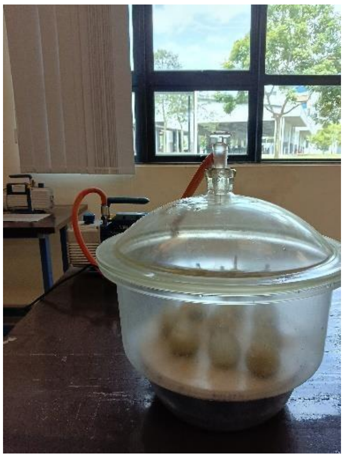

Fig 4 *Equipment of Atterberg limit test*

2.3.3 Hydrometer

The hydrometer test measures the fine fractions of clay and silt in soil passing through a 63 μm sieve. A 50-g soil sample is treated with a dispersion agent and mixed, then placed in a 1 L sedimentation cylinder. The suspension is adjusted to 1000 mL with distilled water and shaken. Hydrometer readings are taken at various time intervals (4 to 450 minutes) to measure the suspension density using Stokes' Law. This method follows British Standard (7).

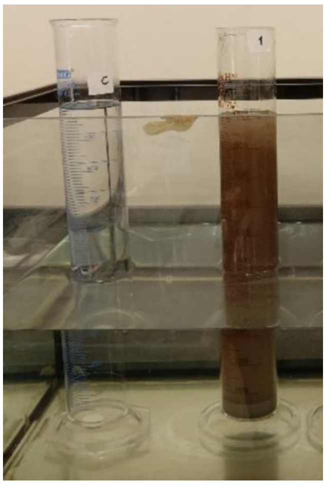

Fig 5 *Equipment of Atterberg limit test*

2.3.4 Scanning Microscopy Electron (SEM)

For this study, Rice Husk Ash (RHA) was sieved to remove large particles, ensuring only fine particles were used. These particles were mounted on a conductive stub with carbon tape and coated with gold to prevent charging during Scanning Electron Microscopy (SEM) imaging. The SEM analysis was conducted at 15 kV, examining the microstructure of RHA at various magnifications to observe porosity and surface morphology.

2.3.5 Standard Compaction Test

The compaction test on the dredged marine soil (DMS) was conducted to ascertain its MDD and OMC. About 3000 g of soil after air-drying was utilized for each test. A 2.5 kg mass standard rammer was dropped from a height of 300 mm to compact the soil in three layers using cylindrical molds, and variant moisture contents (10%, 14%, 16%, 18%,22% and 26%) were added to the soil.

27 blows were compacted to each soil layer for each test. After compaction, the top sample was scratched and soil samples of upper, middle and down layers were taken for oven drying at 105 °C for 24h. Dry density was determined from the bulk density and the water content after compaction.

The process was carried out four to five times at different moisture levels. The data were plotted as dry density vs water content and the compaction curve was generated to find out peak points corresponding to OMC and MDD. The process was follows the British Standard. (8)

Fig 6 *Equipment of Atterberg limit test*

2.3.6 Unconfined Compressive Strength (UCS)

For the DMS, Ordinary Portland Cement (OPC) and Rice Husk Ash (RHA), strength determination was carried out according to (9). In Step 1, dry DMS of 555g was taken for both samples. Cement and RHA were included based on 4%, 6% and 8% cement contents in combination with both 5% and 10% RHA. The best water content was obtained by adding 112.5 g of water after the dry ingredients were mixed together.

Each sample was formed by compaction of soil 185 g each into a cylinder mold in three layers of 62 g with uniform hand pressure to reduce moisture loss. Triplicate specimens were prepared to minimize errors. Curing of prepared samples was carried out in the controlled room at constant temperature and humidity for 7 days.

The sample was tested with a compression testing apparatus that recorded the maximum load at failure. The best combinations for the 7-day samples were 4% cement + 5% RHA, 6% cement + 5% RHA and 8% cement + 5 % RHA with the three highest UCS. These samples were then additionally aged for a further 14 and 28 days with the aim to monitor the evolution of the compressive strength.

(a) **(b)**

Fig 7 (a)*Equipment of Unconfined Compressive Strength (UCS), (b) UCS Machine test*

2.3.7 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test was conducted for the optimal ratio of stabilizing agents for Dredged Marine Soil (DMS). The optimal stabilizing ratios of 5% Rice Husk Ash (RHA) and 6% Ordinary Portland Cement (OPC) were chosen based on early Unconfined Compressive Strength (UCS) tests, which showed these ratios to be the most stable and durable for structural use.

The soil mixture contained 4 kg of stabilized DMS, 198.8 g of RHA, 240 g of OPC, and 765.8 mL of water at Optimum Moisture Content (OMC). The mixture was uniformly mixed and compacted in the CBR mold in three layers, with 56 blows per layer, as follow the British Standard (8). After compaction, the samples were cured for 7 days to complete cement hydration and pozzolanic reactions, followed by immersion in water for 4 days to simulate field conditions.

The CBR test was performed at a standard rate of 1.27 mm/min, with load and penetration depth measured at 5 mm. After testing, the specimen was divided into top, middle, and bottom segments, oven-dried at 105°C for 24 hours to measure moisture distribution, and evaluate the uniformity of compaction and curing.

Fig 8 *Equipment of California Bearing Ratio (CBR)*

3. Result and Discussion

This section discusses the results obtained from laboratory testing conducted on untreated and treated dredged marine soil. The effects of cement and rice husk ash on the physical, mechanical, and microstructural properties of the soil are analyzed. The results are evaluated to determine the optimum stabilisation mix for road subgrade applications.

3.1 Atterberg Limit Test

The liquid limit (LL) is a key parameter in the Casagrande plasticity chart, as it controls the position of soil classification. In this study, the untreated dredged marine soil recorded a relatively low liquid limit of 25.51%, placing the soil within the low plasticity region of the Casagrande chart. This result supports the classification of the untreated soil as clayey silt (CL–ML).(6)

After stabilisation, the liquid limit increased to 34.12%, indicating a change in soil of water interaction due to the presence of cementitious and pozzolanic reactions. However, since plastic limit and plasticity index data were not available for the treated samples, classification using the Casagrande chart could not be applied. Therefore, the liquid limit was used as the primary indicator to evaluate changes in soil consistency after stabilisation. Figure 9 presents the Casagrande plasticity chart for the untreated dredged marine soil.

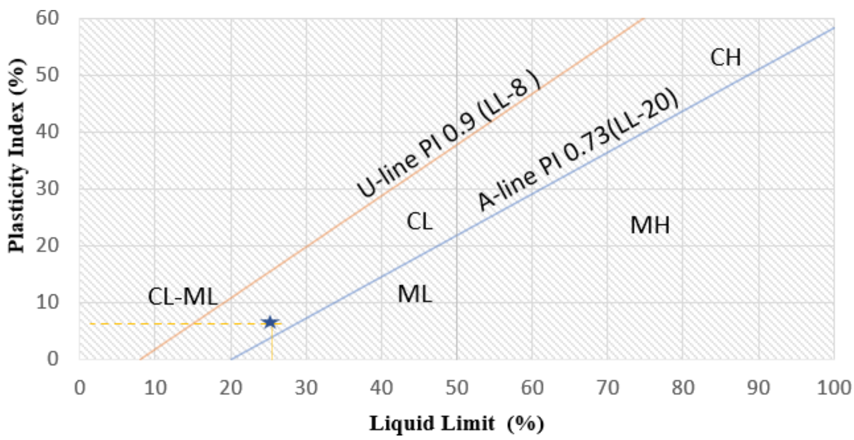

Fig 9 *Casagrande Chart for untreated DMS Endau*

3.2 Hydrometer

The findings of this study align with (10) and (11), who noted that dredged marine soils in Malaysia are primarily sand-silt mixtures with insufficient fines for adequate interparticle bonding. (12) also emphasized that while such soils exhibit good drainage, stabilization is necessary to achieve the required mechanical performance for road subgrade applications. The particle size distribution in this study supports the need for chemical stabilization using cement and RHA to improve bonding and enhance load-bearing capacity.

Figure 10 shows the hydrometer particle size distribution curve, revealing that at a particle diameter of 0.028 mm, about 38.39% of the soil particles were finer. As the particle diameter decreased, the percentage finer reduced, with 24.58% finer at 0.0149 mm and 16.45% at 0.0073 mm. At particle diameters between 0.003 mm and 0.005 mm, the percentage finer stabilized at around 13.71%. This suggests that the soil sample contains a limited proportion of very fine particles, mainly clay-sized particles. The smooth curve indicates consistent sedimentation behavior and reliable results.

Overall, the analysis shows that the soil contains a moderate amount of fine particles, mainly in the silt size range, with a small clay fraction. This particle size distribution suggests moderate plasticity and lower shrink-swell potential compared to highly clayey soils. However, the silt fraction may still affect the soil's strength and compressibility, particularly in saturated conditions.

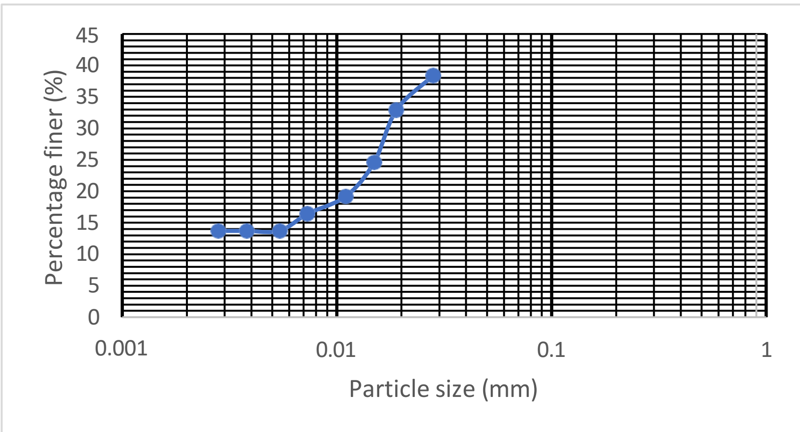

Fig 10 *Graph of Hydrometer DMS Endau*

3.3 Specific Gravity

In this study, the average specific gravity (Gs) value obtained for Dredged Marine Soil (DMS) was 2.5. Thus, the DMS is predominantly made of mineral constituents like quartz and clay minerals with low organic matter. Soils with similar Gs values within the range 2.4-2.7 range for DMS in Malaysia were obtained by other authors like (1),and (13) from other dredging sites in coastal zone. The Gs value confirms the soil used for the present study is representative of the typical dredged marine sediments.

3.4 Scanning Electron Microscopy (SEM)

The SEM analysis of RHA showed that its surface is highly irregular and porous in nature with abundant micro-voids and this improves the surface area which promoted better bonding between soil particles & cement. This uneven surface contributes towards the pozzolanic reaction through capture of hydration products and thus enhances bond between soil and cement by formation of calcium silicate hydrate (C–S–H) gel. (14)

The highly porous and rough surface of RHA provides many active sites that promote effective particle bonding, leading to higher unconfined compressive strength (UCS) over longer curing periods. This observation is consistent with the results in Table 1, which show that the high amorphous silica content of RHA plays a significant role in enhancing the strength development of the stabilized soil.

In addition , the larger pores of the RHA have a higher surface area, it has more space to react with the cement matrix namely Calcium silicate hydrate (C–S–H) which enhances the compressive strength. However, at higher RHA content than its optimal level the porosity and strength would become more due to excessive calcium hydroxide depletion for effective pozzolanic reaction as well poor particle (15). Therefore, an RHA content that allows a balance between the gain in compressive strength and porosity should be determined. The element compositions of the RHA enrichment with silica (46.83%) and oxygen (52.85%), as presented in table 1, confirms a siliceous nature of the RHA and also indicates that a high content of silica is required for its pozzolanic activity. This result was in a good agreement with (16) that rice husk ash classified as silica-rich material can be used to stabilize soil and cement-based materials.

Table 1 *Chemical composition of RHA*

Spectrum 1				
Element	**Line Type**	**Weight %**	**Weight % Sigma**	**Atomic %**
Si	K series	46.83	1.02	33.49
O	K series	52.85	1.03	66.35
K	K series	0.32	0.18	0.16
Total		100.00		100.00

3.5 Compaction Characteristics

Figure 11 shows the relationship between dry unit weight and moisture content for Endau Dredged Marine Soil (DMS). All samples exhibited a similar compaction trend, where the dry unit weight increased with increasing moisture content until the optimum moisture content (OMC) of approximately 18–20% was reached, after which it decreased. The maximum dry unit weight occurred at the OMC, which is consistent with compaction behavior reported in previous studies on dredged marine soils.

At moisture contents below the OMC, the presence of water reduces interparticle friction, enabling soil particles to rearrange more effectively and achieve a denser structure. In contrast, moisture contents exceeding the OMC result in excess water occupying the soil voids, increasing pore water pressure and restricting further densification, thereby reducing the dry unit weight (17). Minor variations in peak dry unit weight were observed due to differences in soil properties, such as particle size distribution and moisture sensitivity (2).

This compaction behavior directly influences the California Bearing Ratio (CBR) performance of Endau DMS. Higher dry unit weight achieved near the OMC leads to improved CBR values due to increased soil density and resistance to penetration. Conversely, compaction beyond the OMC produces lower dry density and reduced strength, resulting in lower CBR values. Similar trends have been reported in earlier studies on dredged marine soils (Marto et al., 2013; Latifi et al., 2020). Table 2 summarizes the optimum moisture content (OMC) and maximum dry density (MDD) values for each sample.

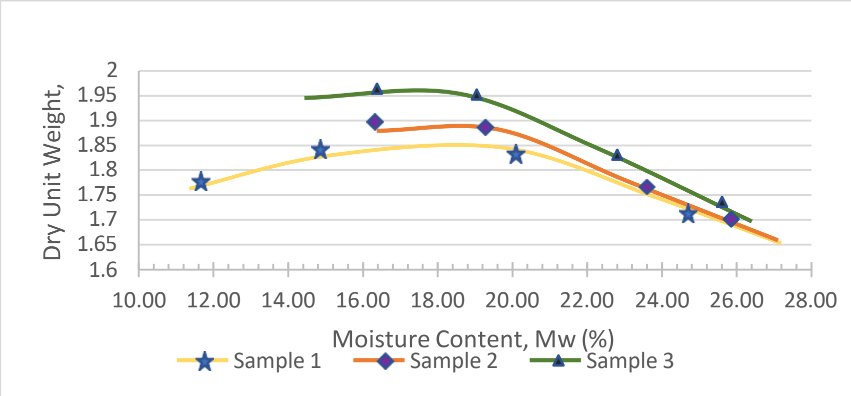

Fig 11 *Graph of Standard Proctor Compaction*

Table 2 *Result of Standard Compaction*

Sample	*OMC (%)*	*MDD (g/cm3)*
Sample 1	19.76	1.845
Sample 2	19.62	1.882
Sample 3	18.50	1.955
Average	19.29	1.894

3.6 Unconfined Compressive Strength (UCS)

The Unconfined Compressive Strength (UCS) test was conducted on both untreated and stabilized Dredged Marine Soil (DMS) to evaluate the effectiveness of Ordinary Portland Cement (OPC) and Rice Husk Ash (RHA) in improving soil strength. The untreated DMS was tested as a control sample to establish baseline strength behaviors. The UCS values for untreated DMS were 111.40 kPa at 7 days, 79.57 kPa at 14 days, and 63.17 kPa at 28 days, indicating very low strength and a reduction in strength with curing time due to high moisture sensitivity, poor inter-particle bonding, and the absence of cementitious compounds. These results are consistent with previous studies on untreated dredged marine soils, which reported similarly low UCS values and confirmed their unsuitability for road subgrade applications without stabilisation. (18). Figure 12 shows the graph of untreated UCS DMS for 7,14 and 28 days.

In contrast, the stabilized DMS showed a significant improvement in UCS with increasing curing period and cement content. At 7 days, the highest UCS was achieved by the 5% RHA + 8% cement mix (462.50 kPa), followed by 5% RHA + 6% cement (426.35 kPa), while the lowest strength was observed for the 5% RHA + 4% cement mix (353.67 kPa). Mixtures containing 10% RHA exhibited considerably lower UCS values (212–291 kPa), indicating that excessive RHA content increased porosity and limited effective pozzolanic reactions. At 14 and 28 days, continued strength development was observed, with the 5% RHA + 8% cement mix reaching 603.77 kPa and 664.23 kPa, respectively, due to ongoing cement hydration and pozzolanic reactions. Figure 13 shows the graph for treated UCS DMS for 7,14 and 28 days.

Overall, the mixture containing 5% RHA and 6% cement was identified as the optimum stabilisation ratio, as it exceeded the minimum UCS requirement of 400 kPa for road subgrade applications while offering improved cost efficiency through reduced cement usage. The comparison between untreated and treated DMS clearly demonstrates that stabilisation using a cement–RHA blend is essential to enhance the load-bearing capacity of dredged marine soil.

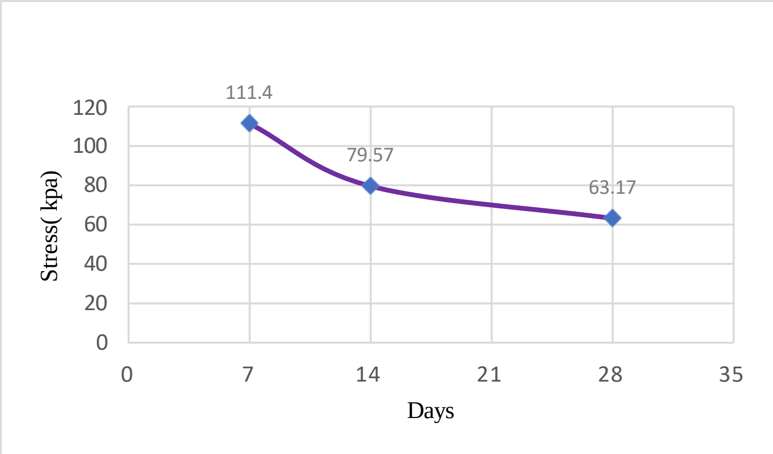

Fig 12 *Graph of DMS UCS untreated*

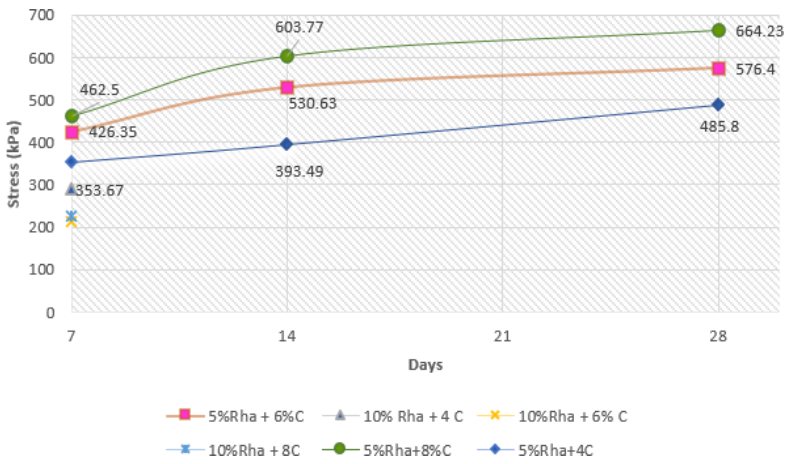

Fig 13 *Graph of DMS UCS treated*

3.7 California Bearing ratio (CBR)

The CBR test results showed measured loads of 3.11 kN and 5.68 kN at 2.5 mm and 5.0 mm penetration for the top surface, corresponding to CBR values of 23.59% and 28.42%. Meanwhile, the bottom surface recorded higher loads of 3.80 kN and 7.80 kN, resulting in CBR values of 28.76% and 39.00%. The higher CBR values at the bottom surface indicate better compaction and improved load-bearing capacity. As the load–penetration curves were smooth and continuous, the higher CBR value at 5.0 mm penetration was adopted for evaluation.

Table 3 *Result top of CBR*

Penetration	2.50	5.00	mm
Load	3.11	5.68	kN
Standard Load	13.20	20.00	kN
California Bearing Ratio	23.59	28.42	%

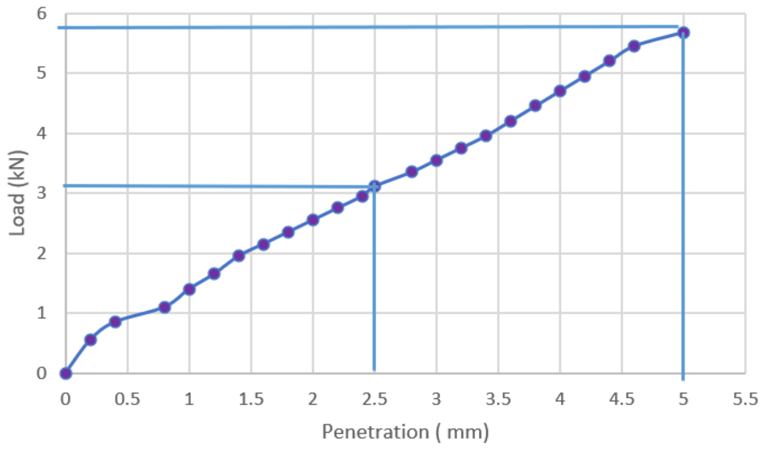

Fig.14 *Load penetration curves for CBR test for top*

Table 4 *Result Bottom of CBR*

Penetration	2.50	5.00	mm
Load	3.80	7.80	kN
Standard Load	13.20	20.00	kN
California Bearing Ratio	28.76	39.00	%

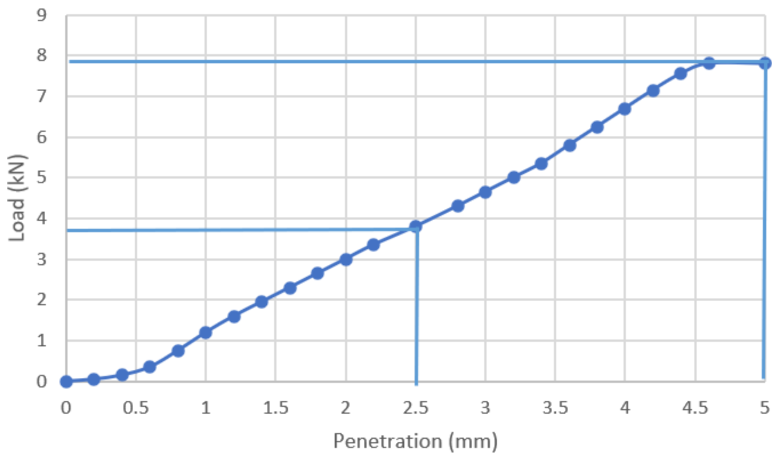

Fig.15 *Load penetration curves for CBR test for bottom*

4. Discussion

The SEM analysis and UCS results from the study indicate the significant role of Rice Husk Ash (RHA) and Ordinary Portland Cement (OPC) in stabilizing Dredged Marine Soil (DMS). SEM examination of RHA revealed that its highly porous structure, with numerous micro-voids, significantly enhances the surface area available for chemical interactions, particularly for pozzolanic reactions. These reactions, driven by the amorphous silica content in RHA, contribute to the formation of Calcium Silicate Hydrate (C-S-H) gel, which is responsible for increasing the strength of the stabilized soil.

The UCS test results show a clear trend of strength improvement with increasing curing time, with the optimum mixture of 5% RHA and 6% cement achieving after 7 days of curing. The UCS of this mix was 426.35 kPa, which meets the minimum requirement for road subgrade applications (400 kPa) as set by the Department of Public Works (19). This mix not only provides sufficient strength but also offers an economical solution by minimizing the use of expensive cement. Additionally, the SEM analysis supports the findings from

UCS testing by highlighting the enhanced bonding between soil particles and cement, which contributes to the improved mechanical strength observed in the UCS results.

The results also indicate that while increasing RHA content beyond 5% leads to reduced strength, primarily due to increased porosity and weaker cement bonding, the 5% RHA + 6% cement mixture strikes an optimal balance between strength, compaction, and cost-effectiveness. The decrease in UCS observed with higher RHA content is consistent with the pozzolanic behavior of RHA, where an excess of RHA may lead to insufficient calcium hydroxide for effective C-S-H formation, weakening the mixture.

5. Conclusion

This study evaluated the effectiveness of Ordinary Portland Cement (OPC) Rice Husk Ash(RHA) in stabilizing Dredged Marine Soil (DMS) for potential application as a road subgrade material. The physical characterization of untreated DMS showed that the soil possesses high moisture content, a specific gravity of 2.5, and low plasticity, classified as clayey silt with low plasticity (CL–ML). Although the untreated DMS exhibited relatively low plasticity, its inherent properties indicated insufficient strength for direct use in road subgrade applications.

The stabilisation process significantly improved the engineering performance of DMS. Microstructural analysis using Scanning Electron Microscopy (SEM) revealed that RHA, with its porous structure and high silica content, contributed to enhanced bonding between soil particles and the cementitious matrix through pozzolanic reactions. These microstructural improvements were consistent with the mechanical test results. The unconfined compressive strength (UCS) results demonstrated that the mixture containing 5% RHA and 6% cement achieved the optimum strength development among all formulations, recording UCS values of 426.35 kPa, 530.63 kPa, and 576.40 kPa at curing periods of 7, 14, and 28 days, respectively. These values exceeded the minimum UCS requirement of 400 kPa for road subgrade materials. In addition, the same mixture achieved a California Bearing Ratio (CBR) value of 39% at a penetration depth of 5.0 mm, indicating adequate load bearing capacity. Overall, the results confirm that Ordinary Portland Cement (OPC) and Rice Husk Ash (RHA) stabilisation is an effective method for upgrading the engineering properties of DMS.

Based on the findings of this study, several recommendations are proposed for future work. Long-term California Bearing Ratio (CBR) testing is recommended to evaluate the durability and load bearing performance of stabilized DMS under prolonged traffic loading conditions. Further investigations involving field scale trials are recommended to validate the laboratory findings and assess the constructability and performance of cement and RHA stabilized DMS under real site conditions. Additionally, future studies may explore different RHA fineness levels and alternative cement replacement ratios to further optimize the stabilisation process while improving sustainability and cost efficiency.

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Author Contribution

The authors confirm contribution to the paper as follows: study conception and design, data collection, analysis, and manuscript preparation were jointly carried out by all authors. All authors reviewed and approved the final manuscript.

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