

Landfill Liners Properties Using Pressmud and Modified Marine Clay

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Abstract

Rapid population growth and changes in lifestyle have resulted in increased solid waste generation, leading to a pressing concern for effective waste disposal. Landfill leachate, containing harmful pollutants, poses a significant environmental risk to landfills. To address this issue, a study was conducted to assess the effectiveness of using pressmud as an absorbent material in landfill liners. The study involved mixing different proportions of pressmud with marine clay and evaluate the physical properties. Results showed that the addition of pressmud significantly increased the compressive strength of the samples. After 7 days of curing, results of the initial Unconfined Compressive Strength (UCS) of the marine clay after curing for 7 days stood at 121.5 kPa. With the additional of 10% pressmud, it rose up to 176.7 kPa and increased to 233.3 kPa with 20% pressmud. The highest was observed in marine clay samples with a pressmud concentration of 20%, where the values rose from 154 kPa at 0 days to 233.3 kPa after 7 days of curing. X-ray Fluorescence (XRF) test analysis revealed that higher concentrations of Calcium oxide, CaO (64.3155%), Magnesium oxide, MgO (2.9759%) and Aluminium oxide, Al₂O₃ (1.0318%) in pressmud, indicating its potential for adsorbing contaminants due to adsorption properties. In conclusion, the pressmud is a potential substance that can be used as a filter to prevent leachates from landfill to contaminate the soil.

1. Introduction

The rapid urbanization and population growth in Malaysia, estimated to reach 32.7 million by 2024, have presented formidable challenges in solid waste management. The escalating solid waste generation, from 33,150 tons in 2012 to 38,699 tons in 2021, with a projected increase to 39,936 tons per day in 2022, underscores the urgency of effective waste handling [1]. Solid waste, typically disposed of in landfills, whether above or underground, poses inherent health and environmental risks. Landfill leachate, containing a range of pollutants such as toxic elements, heavy metals, organic compounds, dissolved methane, fatty acids, sulphate, nitrate, nitrite, phosphates, and calcium, has the potential to permeate the soil, contaminating surface water or groundwater. To address these risks, constant monitoring by solid waste management entities is imperative.

Malaysia faces challenges in waste management, including technological limitations, a shortage of skilled labour, and insufficient infrastructure. The existing landfills, about 137 in number, are largely uncontrolled and outdated, lacking proper soil liners or leachate collection systems, posing a threat to the environment. To ensure ecological safety, the construction of proper landfills becomes necessary, incorporating barriers called liners, covers, and effective waste containment. Conventional materials for landfill liners include compacted clay liners

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(CCLs), geosynthetic clay liners (GCLs), and composite liners (combining CCLs and GCLs). However, the use of synthetic liners, particularly GCLs, has made construction prohibitively expensive, leading to an increased focus on cost-effective alternatives such as compacted clay liners. These liners offer a more budget-friendly solution while still ensuring effective waste containment, contributing to sustainable waste management practices.

The current study proposes the use of a pressmud blend with marine clay, leveraging the easy availability of these materials to create a cost-effective and environmentally friendly liner. Pressmud, traditionally utilized as a fertilizer, has garnered attention for its potential absorbent properties. It has demonstrated the capacity to remove significant amounts of heavy metals, up to 95%, making it a promising material for environmental applications.

This study aims to fill a critical gap by investigating the impact of pressmud on the strength of marine clay and analysing the mineral properties of pressmud and marine clay individually, with a specific focus on their absorbent properties. Understanding how to manage leachate seepage through absorption is crucial for developing guidelines and control measures in landfills. Implementing a robust soil liner construction system is essential for preventing the dissolution of harmful substances into the environment, ensuring human well-being. Therefore, comprehending the strength and absorbent capacity of the pressmud-clay blend becomes pivotal for effective leachate mitigation.

2. Literature Review

The literature highlights the significance of landfills as waste containment systems, aiming to mitigate the environmental and health repercussions of solid waste [2]. [3] state that the severity of environmental hazard increases if the landfill is not equipped with proper engineering solutions, such as liner and leachate collection systems, to protect the environment. Leachate from a landfill undergoes a downward seepage process as waste decomposes. Leachate, a liquid byproduct resulting from the percolation of landfill waste, contains suspended or soluble materials formed during waste degradation [4]. Notably, compacted clayey soils serve as prevalent landfill liners, offering effective isolation of hazardous waste and preventing the migration of heavy metals from landfill leachates into groundwater [5]. [6] emphasize the importance of meeting specific standards for Compacted Clay Liners, including hydraulic conductivity $\leq 1 \times 10^{-9}$ m/s and thickness within the range of 0.6 – 1.5 m. Similarly, the Malaysian Ministry of Housing and Local Government (MHLGM) advocates for the use of earthen liners in landfills, provided they satisfy minimal standards of long-term stability, minimum thickness (50 cm), permeability $\leq 1 \times 10^{-8}$ m/s, and fines content (8%).

Marine clay, predominantly found in coastal corridors, lowland and offshore areas, is characterized by softness, sensitivity, high settlement, and instability, presenting poor soil properties that do not meet engineering requirements [7]. [8] observed the undrained shear strength of marine clay in Kedah, Malaysia, to be less than 25 kPa, indicating its challenges in performance and safety. While [9] showcased the potential use of marine clay as a permeable liner for lateritic soils, [10] highlights the decisive role of physical qualities in determining the strength and stability of marine clay. Coastal clay soil, influenced significantly by moisture content, exhibits expansion with rising moisture levels and contraction with falling levels. Compaction of marine clay samples resulted in a maximum dry density ranging from 1.5 - 1.6 g/cm³ and an optimum moisture content between 18.2% - 25.0%, attributed to the clay minerals' capacity to absorb metals and low hydraulic conductivity.

Presently, soil improvement has incorporated the use of fibres to enhance soil behaviour, as noted by [11]. Past research has investigated the impact of various fibres, such as geo-fibre, jute, nylon, sisal fibre, kenaf fibre, palm fibre, and others, on different soil types. The consensus from these studies, including [11] indicates that fibre inclusion in soil leads to increased ductility, compressive strength, and moisture content. Additionally, it results in reduced maximum dry density, enhanced tensile strength, and improved California Bearing Capacity (CBR).

Within the context of the sugar industry, pressmud, a by-product from sugar cane juice filtration, has gained recognition as a valuable fertilizer [12]. Scholars, such as [13], assert that pressmud plays multiple roles, including preventing soil erosion, regulating soil pH, averting crusting and cracking, improving drainage, acting as a soil conditioner, facilitating soil remediation, and fostering the growth of bacteria and microbes in the soil. [14] reported that pressmud, when used alone, demonstrated the capability to remove nearly 95% to 100% of heavy metals, acting as a natural acid neutralizer. In synthetic acidic wastewater, the presence of pressmud increased the initial pH from below 2 (acidic) to a range between 6 and 8 (more alkaline).

[12] conducted a study analysing pressmud, revealing its adequate carbon content, optimal carbon and nitrogen ratio, and several other favourable properties that justify its suitability for methane production. Further analysis using Field Emission Scanning Electron Microscopy (FESEM) in the studies of [12] illustrated the porous surfaces of pressmud, containing abundant calcium ions, which could aid in the absorption of negatively charged ions such as cyanide and various dyes as shown in Fig. 1.

[15] emphasized the significance of microspores in attracting and binding heavy metal ions from pollutants, contributing to the soil's water holding capacity. Pressmud, characterized by a granular texture with uneven surfaces and pores as shown in Fig. 2, is due to its high organic carbon content, further enhancing its adsorption capacity.

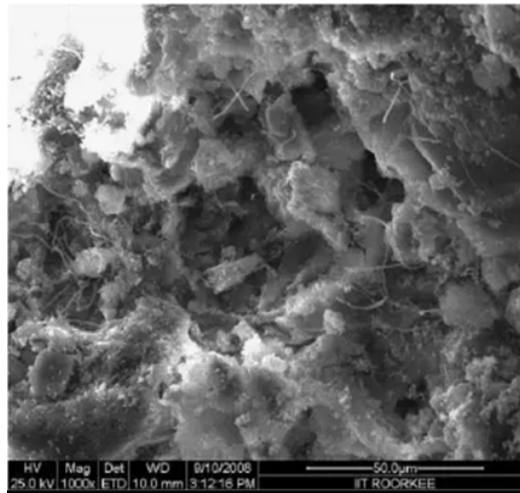


Fig. 1 Micrographs of pressmud sample using FESEM analysis [12]

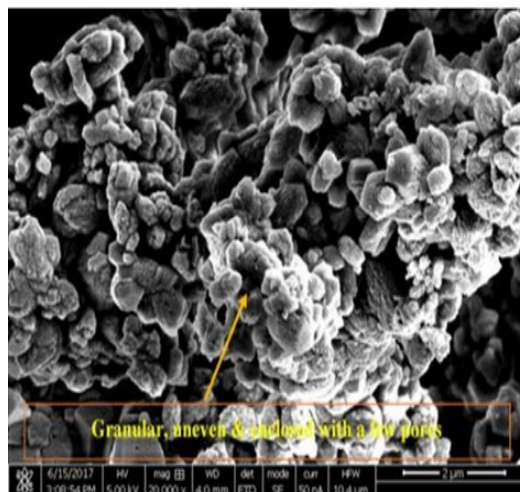


Fig. 2 FESEM images the surface physical morphology of pressmud [15]

3. Research Methodology

This research aimed to assess the impact of incorporating pressmud into marine clay at different ratios, serving the dual purpose of functioning as both a landfill liner and an additive to enhance marine clay's compaction properties. The soil sample, weighing approximately about 15 kg, were collected from Bagan Hailam in Port Klang, was carefully stored in a high-density polyethylene (HDPE) bag to ensure its integrity during transportation as shown in Fig. 3. The subsequent analysis took place at Makmal Mekanik Tanah 2, Universiti Teknologi MARA (UiTM) Shah Alam. The first step involved subjecting the soil sample to a 24-hour oven-drying process, followed by fragmentation into smaller pieces and additional vibration to achieve finer particles. Pressmud, obtained from Central Sugars Refinery Sdn. Bhd. in Selangor, constituted approximately 20 kilograms. After undergoing oven drying at $105 \pm 5^\circ\text{C}$ for 24 hours, the pressmud underwent sieving using a $300\mu\text{m}$ mesh to eliminate any large particles. Both the soil and pressmud samples underwent various physical properties tests, including sieve analysis, hydrometer test, plastic limit, liquid limit, plasticity index, moisture content, and specific gravity. These tests provided a comprehensive understanding of the characteristics of the materials under investigation.

The Unconfined Compression Test (UCT) was conducted to study the effectiveness of the marine clay-pressmud blend as a clay liner. Nine (9) remoulded specimens, each with a diameter of 50 mm and height of 100 mm, were used in the test. All tested specimens were remoulded using the control amount of optimum moisture content (OMC) determined through compaction test procedures. All tests were carried out following the standards outlined in BS 1377:1990. Simultaneously, the mineral properties of pressmud and marine clay were determined through X-ray Fluorescence (XRF) testing, aiming to identify the effectiveness of pressmud as an absorbent. XRF analysis provided valuable insights into the chemical composition in pressmud and marine clay.



Fig. 3 Location of marine clay sample

4. Results and Discussion

The laboratory experiments were conducted to study the physical properties of soil sample and pressmud which included Atterberg Limit test, specific gravity, moisture content and hydrometer test. The unconfined compressive strength (UCS) test was conducted in order to determine the strength value for soil liner application. About nine (9) specimens has been test with different percentages of pressmud (10%, 20%, and 30%). In addition, the mineral properties of pressmud and marine clay is also being examined. The laboratory test data and results were carefully analysed and presented in graphical and tabular formats to facilitate a comprehensive understanding of the findings. The analysis was conducted in alignment with the research objectives and methodology to ensure the attainment of research goals.

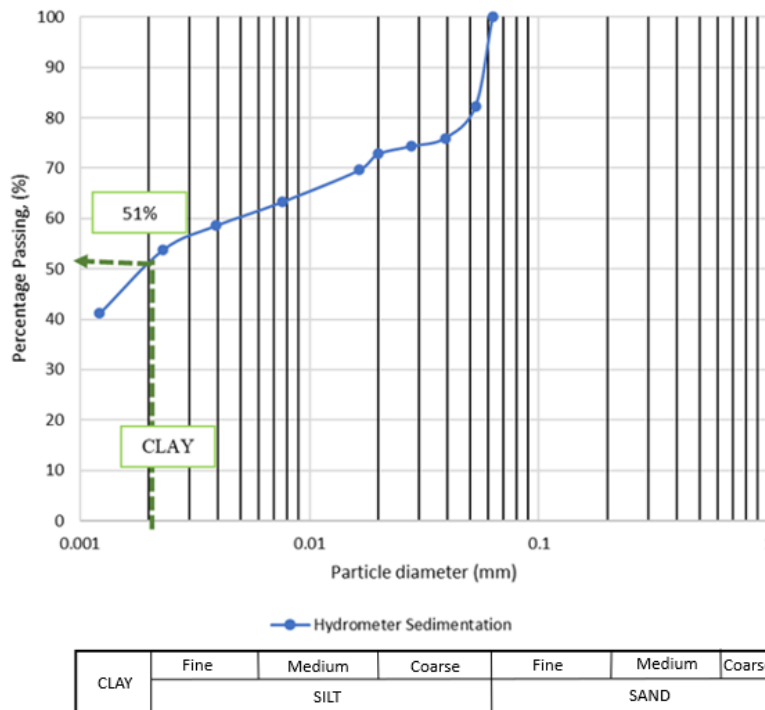


Fig. 4 Particle size distribution curve of marine clay soil

The physical properties tests of marine clay soil were conducted which are particle size distribution, Atterberg limit test, moisture content and specific gravity test. Meanwhile, to determine the pressmud properties, only Atterberg limit and moisture content were tested. Referring to Table 1 and Fig. 4, the marine clay soil sample is dominated by clay (51%) and silt (49%). Hence, from this result, the grain size of the Marine clay is silty CLAY as the percentage of the CLAY is more dominant compared to silt at 51%. [16] cited that the suitable material for liners should contain clay of greater than 10%. [17] recommended that soils used as liner material should have at least 20% fines (fine silt and clay size particles) to achieve hydraulic conductivity values of or less than 1×10^{-7} m/s. Hydraulic conductivity usually decreases with the increase of the content of fine particles [18]. Referring to

Table 1, the marine clay recorded a plasticity index value of 37.44%. In soil classification, the major content of the tested soil was clay, and since the liquid limit value is 62.4%, thus it was classified as clay of high plasticity (CH).

Table 1 Summary of marine clay and pressmud

Material Properties	Marine Clay	Pressmud
Particle Size Distribution (%)		
Silt	49	-
Clay	51	-
Soil Classification	Silty CLAY	
Atterberg Limit (%)		
Liquid Limit	62.4	36.5
Plastic Limit	24.96	18.44
Plasticity Index	37.44	18.06
Soil Classification	Clay of High Plasticity	Clay of Medium Plasticity
Moisture Content (%)	128.40	75.63
Specific Gravity	2.72	-

According to [19], landfill liners often specify a plastic index (P.I.) $\geq 7\%$ and liquid limit (L.L.) $\geq 20\%$. In light of the L.L. and P.I. values, it can be assumed that the soil sample meets these criteria and is suitable for use as a soil liner material. [16] cited the recommended that suitable materials for landfill liners have LL and P.I. values below 90% and 65%, respectively, with a clay fraction greater than 10%. Regarding the Atterberg limits of pressmud, the liquid limit (L.L.) is 36.5%, the plastic limit (P.L.) is 18.44%, and the plasticity index (P.I.) is 18.06%. Generally, pressmud is classified as having medium plasticity. Moisture content of marine clay soil sample was 128.40%.

According to [7], the natural moisture content of marine clay varied from 39% to about 175% depending on the depth and location from which the soil was obtained. Pressmud have low moisture content which is 75.63% compared to marine clay. While the density for soil sample is 2.72 Mg/m³. This value is acceptable to utilize as a landfill liner by referring to the previous research did by [16], [20], [21]. The recommended value of specific gravity for clay should be in the range of 2.67 to 2.90.

Landfill liners are crucial components of waste management systems designed to prevent the contamination of soil and groundwater by leachate, which is the liquid produced as waste decomposes. By subjecting the samples (Marine Clay and Pressmud) to UCT, their compressive strength and load-bearing capacity can be determined. The purpose of conducting Unconfined Compression Testing (UCT) as part of landfill liner design is to assess the mechanical properties and strength of the liner materials. This information is essential for ensuring that the liner material proposed can withstand the weight of the waste and any external forces that may act upon it, such as settlement or surcharge loads.

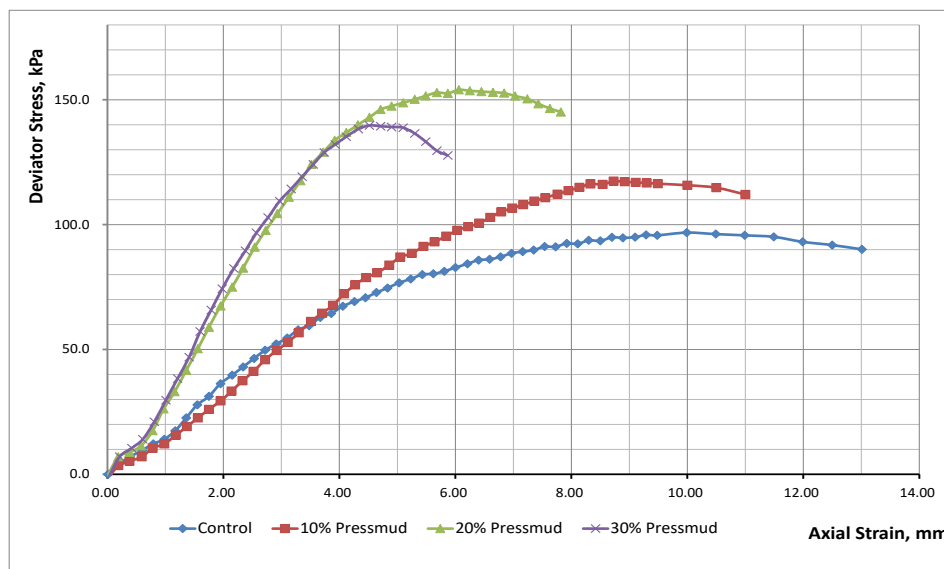


Fig. 5 Deviator stress against axial strain for 0, 10, 20 and 30 % of marine clay mixing with pressmud without curing

Fig 5 shows the deviator stress against axial strain for control, 10, 20 and 30% mixing with pressmud without curing (0 day). Results indicate that the highest value of deviator stress is 154.0 kPa when the specimens mix with 20% of pressmud compared to others. The lowest value of deviator stress was at 96.8 kPa for control specimen. On the other hand, results reveal that the deviator stress against axial strain for 10 and 30% mixing with pressmud was at 117.4 kPa and 139.0 kPa consecutively. Fig. 6 shows the shear strength of Mohr failure envelope for control, 10, 20 and 30% of marine clay mixing with pressmud, where the highest value of undrained shear strength, C_u is at 77 kPa for 20% mixing while the lowest is at 48 kPa for control specimen. Undrained shear strength, C_u for 10 and 30% mixing with pressmud was at 59 and 70 kPa consecutively. At this point, the result reveals that the undrained shear strength C_u start to increase gradually from control to 10 and 20%. However, the undrained shear strength C_u value start to decrease gradually from 20 to 30%. It can be concluded that the value of undrained shear strength C_u for control to 10% increase at 22.9% and from 10 to 20% keep increased at the value of 30.5%. However, the value decreases at 9% when mixing with pressmud at 30%.

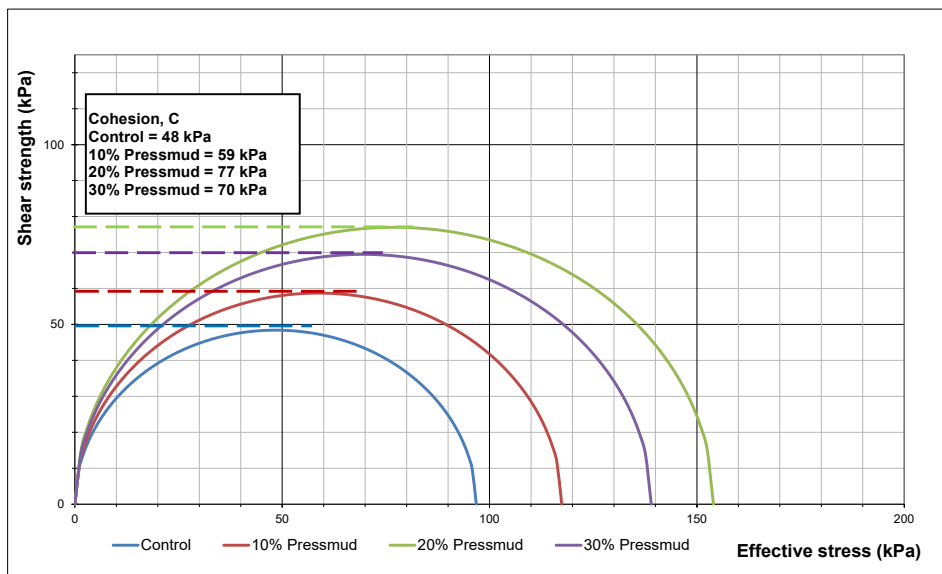


Fig. 6 Shear strength Mohr envelope at failure for 0, 10, 20 and 30 % of marine clay mixing with pressmud without curing

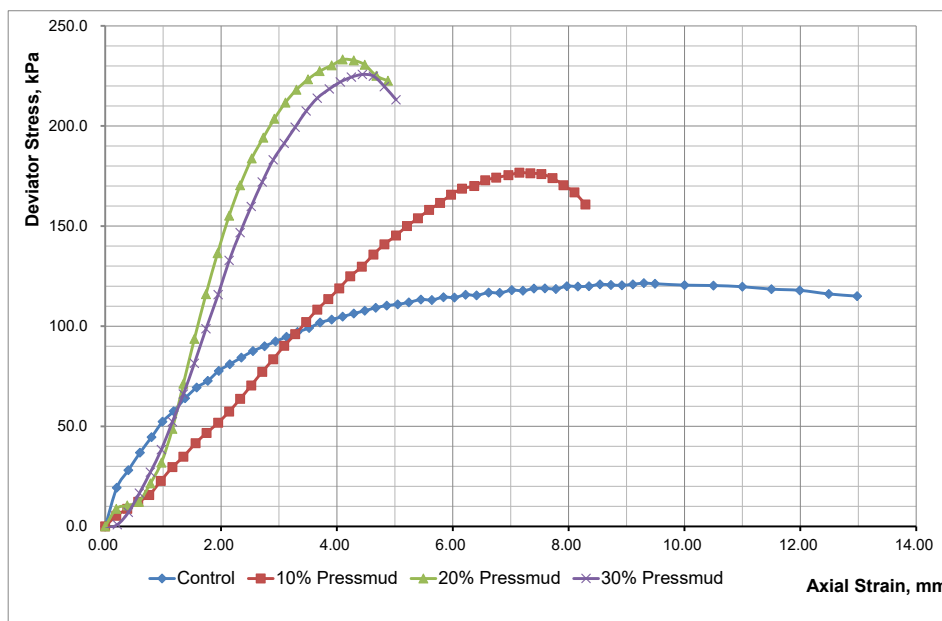


Fig. 7 Deviator stress against axial strain for 0, 10, 20 and 30 % of marine clay mixing with pressmud with 7 days of curing

Fig. 7 shows the deviator stress against axial strain for control, 10, 20 and 30% mixing with pressmud at 7 days of curing. Results indicate that the highest value of deviator stress is at 233.2 kPa when the specimens mix with 20% of pressmud compared to others. The lowest value of deviator stress was at 121.5 kPa for control specimen. On the other hand, results reveal that the deviator stress against axial strain for 10 and 30% mixing with pressmud was at 176.7 kPa and 225.7 kPa consecutively. Fig. 8 shows the shear strength of Mohr failure envelope for control, 10, 20 and 30% of marine clay mixing with pressmud, where the highest value of undrained shear strength, C_u is at 117 kPa for 20% mixing while the lowest is at 61 kPa for control specimen. Undrained shear strength, C_u for 10 and 30% mixing with pressmud was at 88 and 113 kPa consecutively. At this point, result reveals that the undrained shear strength C_u start to increase gradually from control to 10 and 20%. However, the undrained shear strength C_u value start to decrease gradually from 20 to 30%. It can be concluded that the value of undrained shear strength C_u for control to 10% increase at 44.3% and from 10 to 20% keep increased at the value of 33%. However, the value decreases at 3.4% when mixing with pressmud at 30%.

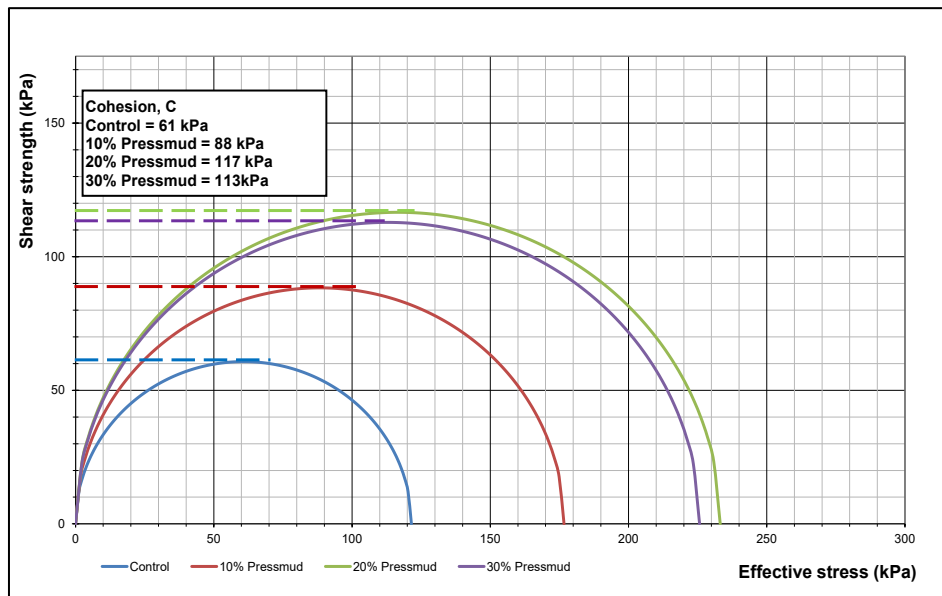


Fig. 8 Shear strength Mohr envelope at failure for 0, 10, 20 and 30 % of marine clay mixing with pressmud with 7 days of curing

Fig. 9 shows that results generally inferred that the compressive strength significantly increases from 0 days to 7 days for all concentrations. The highest increase in compressive strength was observed in marine clay samples with a pressmud concentration of 20%, where the values rose from 154 kPa at 0 days to 233.3 kPa after 7 days of curing.

Other formulations also exhibited notable improvements ranging from 59% to 92% compared to the 0% pressmud concentration. Fig. 6 depicts the combination of Mohr circles for both 0 days and 7 days of sample curing. It shows that there is a substantial increase in cohesion value corresponding to the UCS value from 0 days to 7 days of curing. The highest cohesion value was obtained with a 20% pressmud concentration, measuring 77 kPa at 0 days and 117 kPa after 7 days of curing, reflecting a 52% increment. It is worth noting that the values may further increase with longer curing durations. Based on the results, it can be concluded that increasing the percentage of pressmud added leads to higher increments in both UCS values and cohesion, albeit experiencing a slight decline once the maximum pressmud concentration is reached.

However, the decrease in the compressive strength value from 20% to 30% of pressmud can be attributed to the influence of optimum moisture content. Referring to Table 2, each sample has a distinct moisture content compared to the others. The optimum moisture content (OMC) for 20% pressmud is 25.3%, whereas for 30% pressmud, it is 28%, which represents a substantial difference compared to the other proportions. Optimum moisture content refers to the moisture content at which soil achieves maximum compaction and density, and it significantly affects the compressive strength and cohesion of the soil. High moisture content results in the void spaces becoming filled with excess water, leading to reduce interparticle friction and effective stress. This weakens particle bonding and ultimately decreases the compressive strength of the soil. Furthermore, the excessive amount of pressmud also contributes to the decrease in strength and cohesion. Pressmud can disrupt the natural arrangement and bonding of marine clay particles, interfering with cohesive forces and diminishing particle-particle interactions, which weakens the soil structure. This alteration of soil properties by excessive pressmud can lead to changes in soil's behaviour.

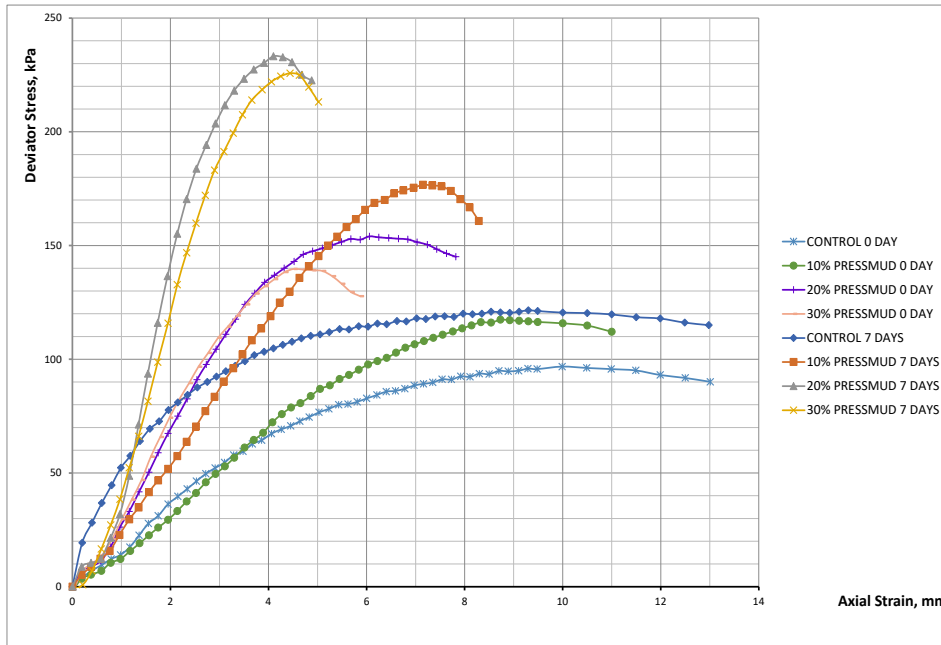


Fig. 9 Combination stress-strain graph for-curing at 0 day and 7 days

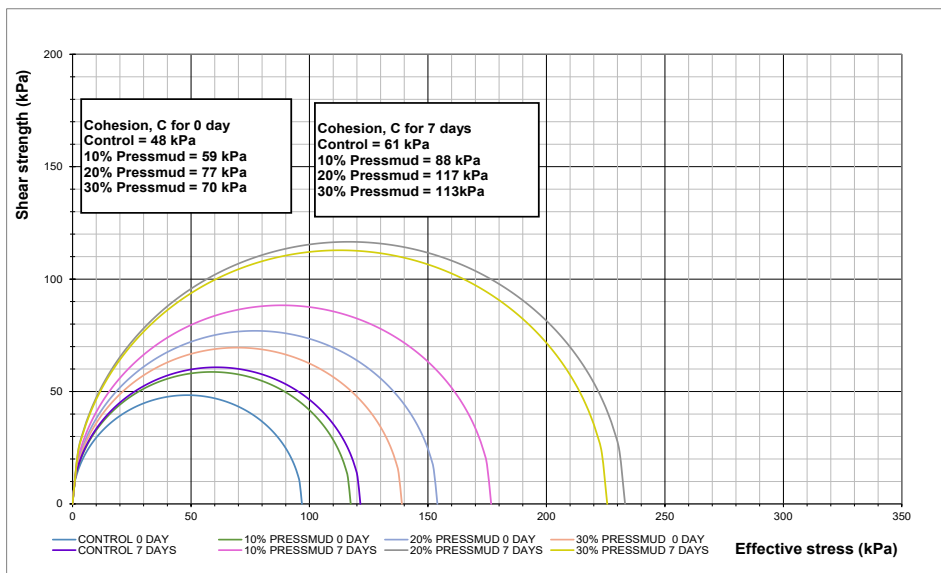


Fig. 10 Combination stress-strain graph for-curing at 0 day and 7 days

Table 2 Unconfined compressive strength for 0 day and 7 days

Sample	OMC (%)	Unconfined Compressive Strength (kPa)	
		Control	7 Days
Control	26	96.8	121.5
10% Pressmud	26	117.4	176.7
20% Pressmud	25.3	154	233.3
30% Pressmud	28	139.7	225.7

Absorbent properties can be determined by evaluating the chemical element composition of the samples by doing XRF analysis. In the case of marine clay and pressmud as landfill liner absorbents, evaluating their chemical properties is crucial to provide insights into their adsorption capacity, specificity for contaminants, stability, compatibility with leachate, and potential environmental impacts. According to [9], specific surface and structural characteristics of minerals determine their ability to retain heavy metals. According to Table 3, the pressmud has

a significantly higher concentration of CaO (64.3155%) compared to marine clay (0.5882%). CaO can aid in the removal of heavy metals through adsorption and precipitation processes. According to Gupta et al. [12], it was found that pressmud are rich in calcium ions where this characteristic can potentially facilitate the absorption of negatively charged ions, including cyanide and different dyes. Pressmud also shows a higher concentration of MgO (2.9759%) compared to marine clay (0.8305%). MgO , also an alkaline compound, can neutralize leachate acidity and exhibits similar adsorption properties to CaO . It can adsorb and react with acidic contaminants, assisting in the removal of heavy metals through adsorption and precipitation mechanisms. In addition, pressmud also contains a higher concentration of Al_2O_3 (1.0318%) compared to marine clay (11.7977%). Al_2O_3 , a versatile adsorbent material, possesses a high surface area and strong adsorption capacity. It can effectively adsorb a wide range of contaminants, including heavy metals, organic compounds, and certain inorganic species.

Table 3 Chemical element composition in pressmud and marine clay

Element Composition	Pressmud	Marine Clay
MgO	2.9759	0.8305
AL2O3	1.0218	11.7977
SiO2	<LOD	40.5854
P2O5	05771	0.00741
S	0.3559	1.3305
Cl	0.0116	1.0414
K2O	<LOD	1.5489
CaO	64.3155	0.5882
Ti	0.008	0.3663
V	0.005	0.0031
Cr	<LOD	0.0043
Mn	0.0212	0.0367
Fe	0.2656	2.3548
Co	<LOD	<LOD
Ni	<LOD	<LOD
Cu	0.0078	0.0041
Zn	0.0018	0.0181
As	<LOD	0.0034
Se	<LOD	<LOD
Rb	<LOD	0.0134
Sr	0.0148	0.006
Y	<LOD	0.0031
Zr	0.0018	0.0203
Nb	<LOD	0.001
Mo	0.0012	0.0006

5. Conclusion

The laboratory tests conducted in this study provided valuable insights into the physical, engineering, and chemical properties of marine clay and pressmud when combined. The marine clay exhibited high plasticity and moisture retention capacity, making it an effective hydraulic barrier. The highest increase in compressive strength and cohesion was observed in marine clay samples with a pressmud concentration of 20%. The addition of pressmud increased the compressive strength and cohesion of marine clay samples. Chemical analysis using XRF revealed variations in elemental composition, pressmud showing higher concentrations of CaO and MgO , while marine clay had a higher concentration of Al_2O_3 . These findings indicate the potential of pressmud as an adsorbent for specific contaminants, particularly heavy metals. Utilizing marine clay and pressmud as leachate adsorbents in landfills can help mitigate contaminant migration and improve overall landfill management to protect the environment.

As for recommendations, conducting hydraulic conductivity tests would assess the effectiveness of pressmud as a hydraulic barrier. Nevertheless, performing an unconfined compression test (UCT) on marine clay with varying percentages of pressmud at different curing durations (1 day, 3 days, 7 days, 14 days and 28 days) would provide insights into their short-term and long-term strength characteristics. Additionally, further analysis of the

adsorption capabilities of pressmud and its compatibility with leachate constituents is necessary. These recommendations will contribute to a better understanding of the potential and suitability of Marine Clay and Pressmud as absorbents in landfill liner systems.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm their contribution to the paper as follows: **study conception and design:** Abdul Samad Abdul Rahman; **data collection:** Shafizah Safingi; **analysis and interpretation of results:** Abdul Samad Abdul Rahman, Shafizah Safingi; **draft manuscript preparation:** Shafizah Safingi, Norbaya Sidek, Mohd Fadzil Arshad. All authors reviewed the results and approved the final version of the manuscript.*

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