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The Effect of Different Mixtures on Desiccation Crack Behaviour and Hydraulic Stability of a Compacted Liner

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ABSTRACT

Landfills utilize leachate containment systems featuring a compacted liner layer with low hydraulic conductivity. Typically, the required hydraulic conductivity is ≤ 1×10^{-5} $cm.s^{-1}$ for final cover liners and ≤ 1×10^{-6} cm/s for bottom liners, to prevent leachate from migrating into surrounding soil and groundwater. This study tested composites made from textile-industry sludge amended with bentonite, lime, and rice husk ash to assess their potential as landfill liner materials. Results indicated that composites with 40% or more bentonite (by mass) mixed with dewatered sludge could meet permeability standards. The addition of 1% lime and 8% rice husk ash further reduced permeability. Incorporating bentonite increased cohesion and lowered the internal friction angle, while lime and rice husk ash raised the internal friction angle and caused fluctuations in cohesion.

1. INTRODUCTION

Leachate is a liquid that percolates through a waste mass, transporting dissolved and suspended substances (Singh & Hendry 2013). To prevent environmental contamination, landfills must be lined with a semi-impermeable barrier designed to contain leachate (Mokhahlane 2013). Many landfills utilize clay liners, which expand when moist and contract when dry (Staub et al. 2011). This swelling and shrinking cycle can compromise the liner's integrity by causing cracks (Chegenizadeh et al. 2025, Vaverková et al. 2018). To minimize cracking, the shrinkage limit for liner materials should not exceed 4% (Maritsa et al. 2016). Consequently, it is crucial to identify a more durable and reliable landfill liner material.

Numerous studies have explored alternative materials, such as coal ash (Nurdin et al. 2016), bentonite (Chaduvula et al. 2017), red mud (Vipulanandan & Leung 1995), among others, to decrease dependence on the overuse of native soil (Puspita et al. 2024). Bentonite is frequently employed as an additive in landfill leachate barriers due to its advantageous properties and low permeability (Kumar & Yong 2002). To reduce costs while satisfying landfill liner performance standards, other materials are often blended with bentonite. In this research, dewatered sludge derived from textile industrial waste serves as the main component, combined with bentonite, lime, and rice husk ash to create a composite layer capable of retaining leachate. Textile industry hazardous waste typically includes sludge or sand that the producer cannot reprocess (Uddin 2021). This waste is generally stored temporarily following incineration before being handed over to a third party.

Consequently, employing dewatered sludge as a landfill liner material necessitates the addition of supplementary materials to enhance its functionality. Ensuring stability is vital in landfill design, impacting both the internal waste mass and the leachate barrier layer (Jones & Dixon 2005, Omidi et al. 1996). The stability of the leachate-retaining layer is inversely related to its permeability (Koerner & Soong 2000). According to standard landfill design practices, the hydraulic conductivity requirement for a compacted final cover liner is usually set at $\leq 1 \times 10^{-5}$ cm.s^{-1}, while bottom liner systems demand a more stringent criterion of $\leq 1 \times 10^{-6}$ cm.s^{-1} to ensure long-term containment effectiveness (Witt & Zeh 2005).

Bentonite demonstrates an exceptionally low permeability coefficient of approximately 1.8×10^{-9} cm.s^{-1}, making it highly effective at preventing leachate infiltration. However, bentonite is highly expansive, shrinking in dry conditions and swelling when exposed to moisture (Holtz 1959). Adding lime has been shown to improve the physical and mechanical properties of the base material, decrease moisture content, and enhance long-term impermeability (Little 1998). When mixed with bentonite for leachate barrier applications, lime can increase the optimum moisture content, lower the maximum dry density, and boost compressive strength (Jain 2024). Additionally, rice husk ash can improve the adsorption of key contaminants such as heavy metals, while reducing permeability and maximum dry density, increasing optimum moisture content, and significantly enhancing compressive strength—up to 200 kN.m^{-2} (Cokca & Yilmaz 2004). This study aims to determine the optimal composition of landfill liner composites made from dewatered sludge amended with bentonite, lime, and rice husk ash. These composites are expected to serve as an alternative material for landfill leachate containment systems.

2. MATERIALS AND METHODS

The samples included dewatered textile-industry sludge waste, bentonite, lime, and rice husk ash (Table 1). The dewatered sludge was sourced from a textile manufacturing plant in Indonesia, while bentonite was obtained from mineral mining facilities. Lime and rice husk ash were purchased commercially. Each material underwent characteristic testing by mixing them at specific compositions. To ensure homogeneous mixtures, the dewatered sludge, bentonite, lime, and rice husk ash were combined using the cone-and-quartering method. The tests conducted included sludge grain size distribution, bentonite swelling, initial moisture content, Atterberg limits, specific gravity, Standard Proctor compaction, and morphological analysis using SEM–EDX.

Table 1: Sample variations.

No	Sample Variation	Variable Code
1	100% S	V1
2	79% S + 20% B + 1% K	V2
3	69% S + 30% B + 1% K	V3
4	59% S + 40% B + 1% K	V4
5	49% S + 50% B + 1% K	V5
6	39% S + 60% B + 1% K	V6
7	71% S + 20% B + 1% K + 8% ASP	V7
8	61% S + 30% B + 1% K + 8% ASP	V8
9	51% S + 40% B + 1% K + 8% ASP	V9
10	41% S + 40% B + 1% K + 8% ASP	V10
11	31% S + 40% B + 1% K + 8% ASP	V11

2.1. Permeability Test

The permeability test was conducted following the falling-head method outlined in AS 1289.6.7.2-2001 (Standards Australia 2001). This technique involves permitting water to pass through a soil specimen connected to a vertical standpipe filled with water. The standpipe is marked with height graduations to enable precise measurement of water level changes and calculation of the volume of water that passes through the soil over time. Before testing, the soil specimen was thoroughly saturated to ensure uniform flow conditions, and the standpipe was filled to a specified initial height. The test began by allowing water to permeate through the soil, with careful observation and recording of the standpipe's water level decline. To ensure consistency and reproducibility, each permeability test was performed in triplicate (n = 3) for each composite variation. The hydraulic conductivity values reported are the average of three independent measurements, with variability expressed as the standard deviation (± SD). The minimal variation among replicates demonstrates the reliability of the falling-head method in assessing the hydraulic performance of the composite materials.

2.2. Desiccation Test

The drying behavior of desiccation cracking was examined in various composite materials under two temperature conditions: a minimum of 25.7°C and a maximum of 40°C. A desiccation test was carried out to identify cracks caused by the drying process and to estimate the hydraulic conductivity of the cracked soil specimen (Puspita et al. 2023). The plate containing dewatered sludge composites with bentonite, lime, and rice husk ash was left to dry, and the changes, including crack formation, were monitored. Photographs of the cracks were captured in both black-and-white and color, then analyzed using MATLAB software to determine the crack area percentage, which was used to calculate the crack width in the composite layer.

2.3. Direct Shear Test

This test was performed to determine the soil's shear strength parameters, specifically cohesion and the internal friction angle. Shear failure occurred in the soil due to the shear force applied by pushing the upper section. Calculations involved converting normal loads into normal stresses and computing shear force and shear stress. These parameters served as the basis for assessing the shear strength of the composite. A shear stress versus normal stress graph was used to determine the cohesion value and internal friction angle of the composite material. Subsequently, composite stability was evaluated using safety factors. The analysis was conducted with GeoSlope/W employing the Morgenstern–Price method, assuming a 30% slope and a layer thickness of 30 cm × 2.

3. RESULTS AND DISCUSSION

3.1. Characteristic Test

The sieve analysis indicated that 99.62% of the dewatered sludge was classified as sand, with the remaining 0.38% identified as clay and silt. The pure bentonite swelling test revealed a free swell index (FSI) of 390%. Bentonite is known to expand in distilled water, and this expansion helps fill voids between dewatered sludge particles, thereby enhancing soil density (Masihi & Gholikandi 2020, Qin et al. 2023). An FSI of 390% signifies that the bentonite expanded approximately 39 times its original volume. Higher clay content increases soil cohesion and decreases the shear angle (Bozbey & Guler 2006). These effects occur because sand is a non-cohesive soil, especially under dry conditions, and lacks well-defined plasticity boundaries (Nhan et al. 1996, Rubey, 1933). In terms of permeability, a greater sand proportion typically leads to increased permeability (Churchman et al. 2006, Revil & Cathles III, 1999). The Atterberg limit tests showed that not all composite variations demonstrated plastic behavior. Composites with at least 30% bentonite exhibited plasticity, evidenced by their plasticity index. Specifically, the composite with 30% bentonite had a plasticity index between 0.48% and 1.1%, while those with 40%, 50%, and 60% bentonite showed indices of 16.21%, 11.5%, and 14.01%, respectively.

The initial moisture content across all composites ranged from 19.24% to 36.56%. The addition of bentonite caused an increase in moisture content in a non-linear fashion. Lime application also led to a significant rise in moisture content. Conversely, rice husk ash reduced the moisture content compared to the composite containing dewatered sludge, bentonite, and lime. The inclusion of bentonite tended to elevate specific gravity because its swelling fills pores within the dewatered sludge matrix. However, the performance of bentonite was diminished by the addition of lime and rice husk ash, resulting in a subsequent decrease in specific gravity. The Standard Proctor test yielded varying values of optimum moisture content (OMC) and maximum dry density (MDD) among the composites. Notably, composite V1, which lacked bentonite, exhibited the highest OMC and the lowest MDD, reflecting the dewatered sludge's poor water interaction and its need for higher moisture to reach maximum density. The addition of lime increased both OMC and MDD. When rice husk ash was incorporated, OMC decreased while MDD increased, likely due to rice husk ash's role in promoting hardening, thus making the material stiffer and denser. Lime also accelerates hardening, especially before the composite absorbs substantial water.

3.2. Permeability Behavior of the Composites

The initial experiments compared $MgCl_2$ and MgO as sources of magnesium over a pH range of 6–11. The findings showed that $MgCl_2$ consistently surpassed MgO in nutrient removal efficiency. Maximum ammonium reduction was observed at pH 9, while phosphate removal peaked at pH 10. At these optimal conditions, over 70% of phosphate and nearly 60% of ammonium were removed from the solution. The comparatively poorer performance of MgO can be explained by its limited solubility, which results in a slower release of Mg^{2+} ions, delaying nucleation and crystal growth. Conversely, $MgCl_2$ supplies an immediate and high concentration of soluble magnesium, promoting rapid supersaturation and precipitation. The pH dependency aligns with established research indicating that struvite crystallization is heavily influenced by solution chemistry (Petal Battistoni et al. 1997). At near-neutral pH levels (6–7), minimal precipitation occurs due to restricted PO_4^{3-} ion availability. Under highly alkaline conditions (>10.5), the decrease in removal efficiency may be due to competing precipitation of calcium phosphate and amorphous phosphate species. Therefore, pH 9–10 appears to be the optimal range for struvite precipitation in composting leachate, corroborating prior studies on wastewater and digestates (Kabdaslı et al. 2000, Yetilmezsoy & Sapci-Zengin 2009).

The permeability (hydraulic conductivity) test was carried out to assess the composite material's capacity to allow horizontal and lateral water flow through the soil, aiding in the selection of an appropriate composite for a landfill liner (Ng et al. 2016, Scalia IV & Benson 2011). Specimens prepared at the optimal dry density, determined

Table 2: Permeability test results.

No	Sample Variation	Hydraulic Conductivity [$cm.s^{-1}$]
1	100% S	$(1.36 \pm 0.05) \times 10^{-2}$
2	79% S + 20% B + 1% L	$(6.42 \pm 0.21) \times 10^{-5}$
3	69% S + 30% B + 1% L	$(6.42 \pm 0.18) \times 10^{-5}$
4	59% S + 40% B + 1% L	$(9.79 \pm 0.32) \times 10^{-7}$
5	49% S + 50% B + 1% L	$(1.83 \pm 0.07) \times 10^{-7}$
6	39% S + 60% B + 1% L	$(8.16 \pm 0.29) \times 10^{-7}$
7	71% S + 20% B + 1% L + 8% RHA	$(3.03 \pm 0.11) \times 10^{-5}$
8	61% S + 30% B + 1% L + 8% RHA	$(3.55 \pm 0.13) \times 10^{-5}$
9	51% S + 40% B + 1% L + 8% RHA	$(1.17 \pm 0.04) \times 10^{-6}$
10	41% S + 40% B + 1% L + 8% RHA	$(2.34 \pm 0.08) \times 10^{-6}$
11	31% S + 40% B + 1% L + 8% RHA	$(1.02 \pm 0.03) \times 10^{-6}$

from the Proctor test, were used for the test, which was conducted using the falling-head method. The results of the permeability tests are shown in Table 2.

The decrease in hydraulic conductivity observed in the composite variations is mainly due to microstructural changes within the pore network. Bentonite's swelling capacity plays a key role; when hydrated, bentonite particles expand and fill the voids between dewatered sludge particles, leading to smaller pore sizes and reduced pore connectivity. This swelling markedly restricts water flow pathways and thereby lowers the permeability of the composite materials (Horpibulsuk et al. 2011, Qiang et al. 2014). Additionally, composites containing 30% or more bentonite show an increased plasticity index, which further reduces permeability. Higher plasticity indicates greater water retention and stronger interparticle bonding, impeding the formation of continuous flow channels within the compacted matrix. Consequently, hydraulic conductivity declines as bentonite content increases.

The addition of lime and rice husk ash further alters the pore structure through physicochemical reactions. Lime promotes flocculation and pozzolanic activity, leading to the formation of cementitious compounds such as calcium silicate hydrate (C–S–H) that strengthen interparticle bonds and decrease pore connectivity. Rice husk ash, rich in amorphous silica, reacts with calcium from lime to enhance the composite matrix. These reactions improve the structural integrity and further reduce hydraulic conductivity. However, replacing part of the bentonite with rice husk ash may diminish swelling contributions, which could explain the permeability variations observed across different compositions.

3.3. Desiccation Crack Analysis

Crack testing was performed using MATLAB software, which involved converting the original RGB image into a binary format. The crack area was then determined through the crack intensity factor (CIF) formula, allowing quantification of the crack extent across the entire image. Composite V1, composed of 100% dewatered sludge, could not be assessed in the desiccation test because MATLAB software could not detect any cracks. This limitation is because pure dewatered sludge contains granular particles, commonly known as aggregates, which are dispersed and non-plastic (see Fig. 1). This observation is supported by preliminary grain size analysis, revealing that the dewatered sludge consists of 99.62% sand. Sand is classified as a non-cohesive, easily loosened soil under dry conditions, and therefore lacks plasticity.

For composites other than V1, adding bentonite, lime, and rice husk ash from Day 0 to Day 9 reduced the water content and induced desiccation, leading to cracks on the sample surface at the lowest temperature (25.7°C). The inclusion of bentonite, 1% lime, and 8% rice husk ash also caused a decrease in the CIF value, as depicted in Fig. 2.

The images were taken on the 9th day at the minimum temperature. The CIF values were undefined for V1 and were 0.72% (V2), 2.58% (V3), 2.37% (V4), 2.67% (V5), and 2.78% (V6). For the remaining composites, the CIF values were 0.64% (V7), 2.37% (V8), 1.10% (V9), 1.16% (V10), and 1.20% (V11). The largest CIF value occurred in V6, which consisted of 39% dewatered sludge, 60% bentonite, and 1% lime, while the smallest CIF value occurred in V7, which consisted of 71% dewatered sludge, 20% bentonite, and 1% lime.

The addition of 8% rice husk ash was shown to decrease the CIF value. Incorporating rice husk ash into composites with expansive soils helps reduce the soil's swelling potential. When combined with lime, rice husk ash acts as a binding agent within the aggregate structure (Çoruh &

Fig. 1: Composite V1 from Day 0 to Day 9 (cracks cannot be detected).

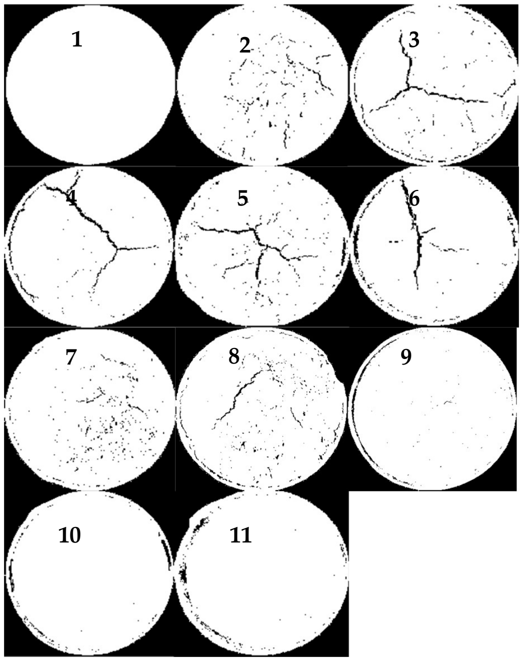

Fig. 2: Binary image of cracks at the minimum temperature on Day 9.

Ergun 2010, Sua-Iam & Makul 2013). This effect is due to the pozzolanic properties of rice husk ash, which react with the expansive soil to create a stiffer, more rigid composite matrix. The silica content in the pozzolanic material reacts with quicklime, improving interparticle bonding and enhancing overall strength. Additionally, rice husk ash helps minimize shrinkage, thus decreasing crack formation within the composite (Amran et al. 2021, Kaya & Durukan 2004). Shrinkage mitigation occurs because rice husk ash reduces the maximum dry density while increasing the optimum moisture content (OMC), leading to a more plastic and workable composite behavior.

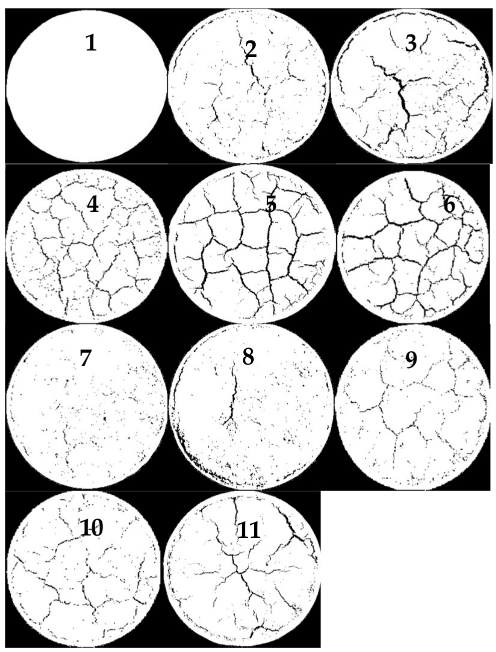

Fig. 3: Binary image of cracks at the maximum temperature on Day 6.

Table 3: Desiccation crack test results.

Variation	CIF [%]	
	27°C	40°C
V1	-	-
V2	2.55	2.25
V3	2.58	4.96
V4	2.38	4.00
V5	2.68	5.70
V6	2.78	6.21
V7	0.64	1.51
V8	2.37	3.10
V9	1.10	2.31
V10	1.16	2.71
V11	1.21	3.41

At an elevated temperature of 40°C, all V2–V11 composite variations containing bentonite, lime, and rice husk ash were tested over a curing period from day 0 to day 6. The results indicate a continuous decrease in moisture content across the V2–V11 samples, leading to desiccation and the subsequent formation of surface cracks, as illustrated in Fig. 3.

Images taken on the 6th day produced CIF values that were undefined for V1 and were 2.25% (V2), 4.96% (V3), 4.00% (V4), 5.70% (V5), 6.21% (V6), 1.51% (V7), 3.10% (V8), 2.31% (V9), 2.71% (V10), and 3.41% (V11). The results of the desiccation crack analysis are presented in Table 3.

At both temperature conditions, composites V2, V8, V9, V10, and V11 demonstrated CIF values below 4%. In contrast, the remaining composites showed CIF values exceeding 4%. The lowest crack intensity was recorded in composite V7, with CIF values of 0.64% at the minimum temperature and 1.51% at the maximum temperature.

3.4. Shear Strength and Stability Analysis

The results indicate that as the bentonite content increased, the internal friction angle generally decreased while cohesion rose. These two parameters are key indicators of the shear strength of the composite materials (Budihardjo et al. 1921). The internal friction angle reflects the stability of the composite in terms of frictional resistance, whereas cohesion represents the bonding force between particles that enhances the material's strength. Notably, the changes in the internal friction angle and cohesion were neither linear nor uniform. The decline in the internal friction angle can be attributed to the fact that bentonite fills the spaces between aggregates, thereby reducing interparticle friction. Conversely, cohesion increased at higher bentonite contents because bentonite functions as a binding agent within the composite structure.

The addition of lime to the composite materials resulted in changes to the internal friction angle and a reduction in cohesion. Lime–aggregate interaction facilitates contact between lime and clay minerals, triggering an ion-exchange reaction that produces calcium silicate gel. This gel, which is insoluble in water, induces particle flocculation, decreasing pore spaces within the aggregates and enhancing overall structural stability (Rubinos et al. 2015). In lime and rice husk ash composites, the internal friction angle increased, while cohesion exhibited irregular fluctuations. These variations in cohesion may be attributed to uneven shear displacement rates, though the overall changes were not significant. The inconsistent and low cohesion response could be due to an imbalanced rice husk ash-to-lime ratio, leading to a non-optimal and uneven reaction across the composite samples.

It was observed that the curing behavior significantly influenced the shear strength parameters, specifically the internal friction angle and cohesion, across all composite variations. When cured using leachate, the composites demonstrated a progressive increase in both parameters over four hours, indicating enhanced mechanical stability and resistance to shear deformation. Simultaneous changes in the internal friction angle and cohesion suggest stronger particle bonding and improved frictional resistance within the composite matrix. The observed increases in shear strength parameters highlight the potential for these composites to serve as leachate-retaining layers. Their ability to maintain and even improve stability under leachate-curing conditions indicates that exposure to leachate does not undermine their structural integrity. Consequently, leachate intrusion will not diminish the composites' mechanical strength, confirming their suitability for long-term use in waste management systems as containment and barrier elements.

The GeoSlope/W analysis aimed to assess the factor of safety of the composite material when used as a leachate barrier layer. The stability was evaluated using the Morgenstern–Price method, considering a 30% slope inclination and a liner thickness of 30 cm (two layers). The model assumed homogeneous material properties derived from laboratory direct shear tests, including cohesion and internal friction angle, without external surcharge or waste overburden pressure. Pore water pressure conditions were simulated under steady-state assumptions, without additional hydraulic head. A slope is deemed stable when the factor of safety exceeds 1.25 (Herrmann et al. 2009). The composites made of dewatered sludge and bentonite generally showed a decreasing trend in factor of safety. For example, the V1 composite, made entirely of 100% dewatered sludge, had a factor of safety of 14. The high factor of safety values in this study were primarily due to the shallow slope geometry, limited liner thickness, and high cohesion measured under laboratory conditions. These assumptions tend to produce conservative stability results, especially without external loads. The reduction in factor of safety with increasing bentonite content is linked to decreased shear resistance, reflected by lower cohesion and internal friction angles. High safety factors are mainly driven by elevated internal friction angles and cohesion. Conversely, composites with lime and rice husk ash showed a different trend. Adding lime, alone or combined with rice husk ash, increased the factor of safety, reaching a maximum of 21.67. However, this maximum represents idealized conditions and does not consider long-term factors such as waste settlement, dynamic loading, or full saturation, which could lower the safety margin in real-world applications. Additionally, leachate curing contributed to higher factor of safety values, improving cohesion and internal friction angles across all composites. Under the modeled assumptions, all combinations satisfied the stability criteria, indicating a low potential for slope failure in controlled analytical conditions.

3.5. Microstructural Analysis (SEM–EDX)

SEM observations revealed the presence of surface cracks within the composite materials. At higher magnification, micrographs demonstrated that bentonite particles progressively filled and bridged the crack spaces, resulting in a denser and more compact microstructure. This infilling behavior reduced crack continuity and limited the formation of interconnected pore channels, thereby supporting the observed decrease in hydraulic conductivity. However, the addition of lime and rice husk ash altered the swelling behavior of bentonite. The interaction between calcium from lime and silica-rich rice husk ash promoted pozzolanic reactions, leading to the formation of cementitious compounds. EDX analysis confirmed the presence of silica (Si), calcium (Ca), and aluminum (Al), consistent with oxides such as SiO_2, Al_2O_3, and CaO. These components contribute to the development of secondary bonding phases that enhance matrix stiffness and structural integrity. While these reactions improve mechanical strength, they may also partially restrict excessive bentonite swelling, which explains the variation in crack closure observed among different composite formulations. It is important to note that the SEM analysis in this study was primarily qualitative. Quantitative measurements of pore size distribution or crack width were not conducted. Therefore, the SEM–EDX findings serve as microstructural support for the macroscopic permeability and shear strength results, rather than providing direct quantitative evidence. Future research incorporating image-based pore analysis or advanced porosimetry techniques is recommended to better quantify the evolution of the pore network.

3.6. Environmental Risk Considerations

The use of dewatered textile sludge as a component in landfill liner materials warrants careful evaluation of potential

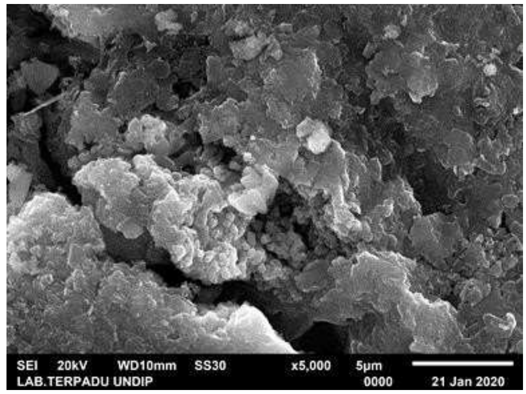

Fig. 4: Composite SEM results.

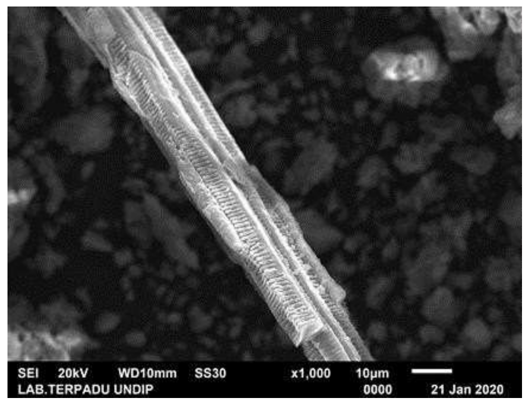

Fig. 5: SEM results of rice husk ash.

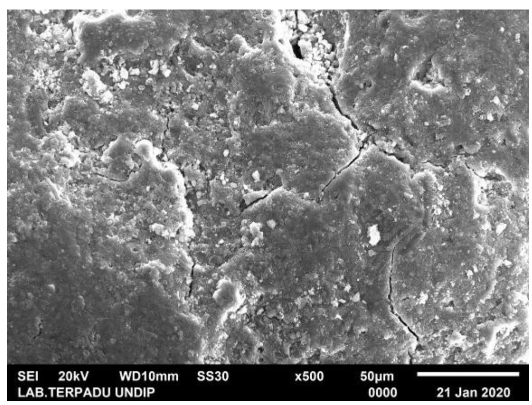

Fig. 6: Composite surface SEM results.

environmental risks. Textile sludge may harbor residual contaminants such as heavy metals, dye compounds, and other industrial by-products, depending on the wastewater treatment processes at the source facility. These contaminants could pose risks if mobilized over long-term field conditions. In this study, leachability tests like the Toxicity Characteristic Leaching Procedure (TCLP) or other standardized methods were not performed, leaving the potential release of heavy metals or other pollutants from the composite liner unquantified. This limitation should be considered when assessing the suitability of the material for large-scale application. Nonetheless, incorporating bentonite, lime, and rice husk ash can aid in contaminant immobilization through various mechanisms. Bentonite's high cation exchange capacity and adsorption potential enable it to retain metal ions within its interlayer structure. Lime increases pH, facilitating the precipitation of metal hydroxides and thus reducing metal solubility. Additionally, pozzolanic reactions between calcium compounds and silica-rich rice husk ash can encapsulate contaminants within a denser cementitious matrix, restricting their mobility. These stabilization processes are well-documented in solidification–stabilization methods for contaminated materials. Future research should incorporate comprehensive leachability evaluations, such as TCLP or long-term column leaching tests, to ensure environmental safety and regulatory compliance of the composite liner. Such studies are crucial to verify that the improved mechanical and hydraulic properties observed also provide adequate environmental protection under operational field conditions.

4. CONCLUSIONS

Dewatered sludge in its pure form exhibits the lowest initial moisture content, the lowest specific gravity, and lacks plasticity. The properties of the composites vary according to the composition and proportion of dewatered textile-industry sludge used. The addition of bentonite, lime, and rice husk ash results in decreased permeability, increased plasticity, and greater shrinkage strength, which can lead to cracking. Incorporating bentonite into dewatered sludge tends to reduce the internal friction angle while increasing cohesion. Conversely, the addition of lime and rice husk ash causes fluctuations in cohesion and elevates the internal friction angle. The safety factor of composites containing bentonite also diminishes. The desiccation process of these composites involves moisture loss during drying, which induces surface cracking. Composites with rice husk ash show lower crack intensity factors, indicating enhanced resistance to desiccation cracking under varying temperature conditions. Variants suitable as alternative cover liners—meeting the shrinkage limit criterion of less than 4% to prevent cracking and having permeability values at or below 1×10^{-5}—include V10 (41% dewatered sludge, 50% bentonite, 1% lime, 8% rice husk ash). For bottom liners, V4 (59% dewatered sludge, 40% bentonite, 1% lime) is recommended. While the mechanical and hydraulic performance of these composites is promising, further study into the leaching and environmental safety of dewatered textile sludge is essential to ensure long-term regulatory compliance. Comprehensive leachability testing is advised prior to field-scale application.

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