Crafting Excellence: The Art of Mastering Liner Construction

L. C. Lentswe[1], T. Ramoleko[2]

[1]Knight Piésold (Pty) Ltd, Pretoria, Gauteng, clentswe@knightpiesold.com
[2]Knight Piésold (Pty) Ltd, Gaborone, Southeast, tramoleko@knightpiesold.com

Abstract

Liner integrity within a Tailings Storage Facility (TSF), is particularly a burning issue within the context of the modern era of enhanced environmental awareness and regulatory control. Given the sheer number of concerns in mine waste and water management, the focus on TSF and its lining is crucial due to its direct correlation with environmental protection, community safety, and regulatory compliance. The Global Industry Standard on Tailings Management (GISTM) presents another perspective to this issue underlining the significance of TSF lining. Indeed, lining systems are vital to mitigating the risk of environmental contamination and ensuring the safe containment of tailings. The implications of a TSF operating without sufficient lining could be daunting, as it exposes ecosystems to potential pollution and jeopardizes water resources. This paper aims to equip the reader with the knowledge and confidence to excel in the world of construction by shedding light on the do's and don'ts, unwritten rules, challenges, and solutions associated with TSF liner construction and maintenance.

Keywords: *Liner Construction, Tailings Storage Facility (TSF), Regulatory Compliance, Quality Control, Quality Assurance.*

1 Introduction

Liner systems are pivotal in constructing and managing tailings storage facilities, acting as a barrier between tailings and the environment to prevent potential contamination. High-density polyethylene (HDPE) is commonly used for geomembrane liners due to its reliability and durability. Regulatory compliance and adherence to industry standards are crucial in designing and constructing liner systems for tailings storage facilities.

This paper aims to provide a beginner-friendly introduction to HDPE liners, elucidating fundamental aspects of HDPE liner construction, including site preparation, installation techniques, and quality assurance, practical insights and best practices, common challenges and solutions serving as a valuable resource for those involved in HDPE liner construction projects.

2 Regulatory compliance and standards

Regulatory compliance and adherence to industry standards are paramount for ensuring facility safety and environmental sustainability. Most TSFs are lined due to stringent local waste regulations that mandate this requirement. The Global Industry Standard on Tailings Management (GISTM) is widely adopted because it provides comprehensive guidelines for managing tailings facilities, emphasizing the importance of minimizing environmental risks throughout the TSF lifecycle, which in this case encompasses the use of liners and seepage control measures (refer to GISTM principle 3 requirement 3.2).

In South Africa, stringent local waste regulations are crucial for the design and management of TSFs to prevent environmental contamination. The National Environmental Management: Waste Act 59 of 2008 and its associated regulations mandate that TSFs must be lined to minimize the risk of seepage and ensure the protection of groundwater and surrounding ecosystems. Additionally, the South African National Standards (SANS) provide specific requirements tailored to local conditions. SANS 10409, for example, outlines the requirements for geosynthetic materials used in environmental applications, including liners for waste containment. These regulations stipulate that TSFs must be lined to minimize the risk of seepage and ensure the protection of groundwater and surrounding ecosystems.

Moreover, several international standards are adopted to enhance the quality, performance and safety of TSF management. These standards such as American Society of Testing Materials: miscellaneous materials (ASTM D) and Geosynthetic Research Institute (GRI) provide critical guidelines and testing methods for ensuring the integrity, performance, and safety of geomembrane liners. These standards help during the construction of a lined TSF by ensuring that the geomembranes are properly manufactured, installed, and tested to prevent defects and leaks. This ensures that the liners are durable, reliable, and effective in containing tailings and protecting the environment from potential contamination.

3 Quality control and quality assurance

Quality control and quality assurance in liner construction includes project and field quality control and quality assurance. Project quality control encompasses various elements crucial for ensuring the successful execution of a project. These include assessing project conditions, verifying material warranties, evaluating geomembrane installation warranties, overseeing delivery, storage, and handling procedures, assessing installer qualifications, implementing source quality control measures, and conducting geomembrane quality control checks.

Project quality assurance includes establishing protocols for documentation, conducting installation and testing procedures, and assessing subgrade conditions to ensure comprehensive oversight and accountability.

Field quality control encompasses subgrade preparation, geomembrane placement, and welding procedures to verify compliance with design specifications. Regular inspections and testing are crucial for assessing the quality and integrity of the liner system. Here is a sequence one can follow on field quality control and quality assurance (Figure 1).

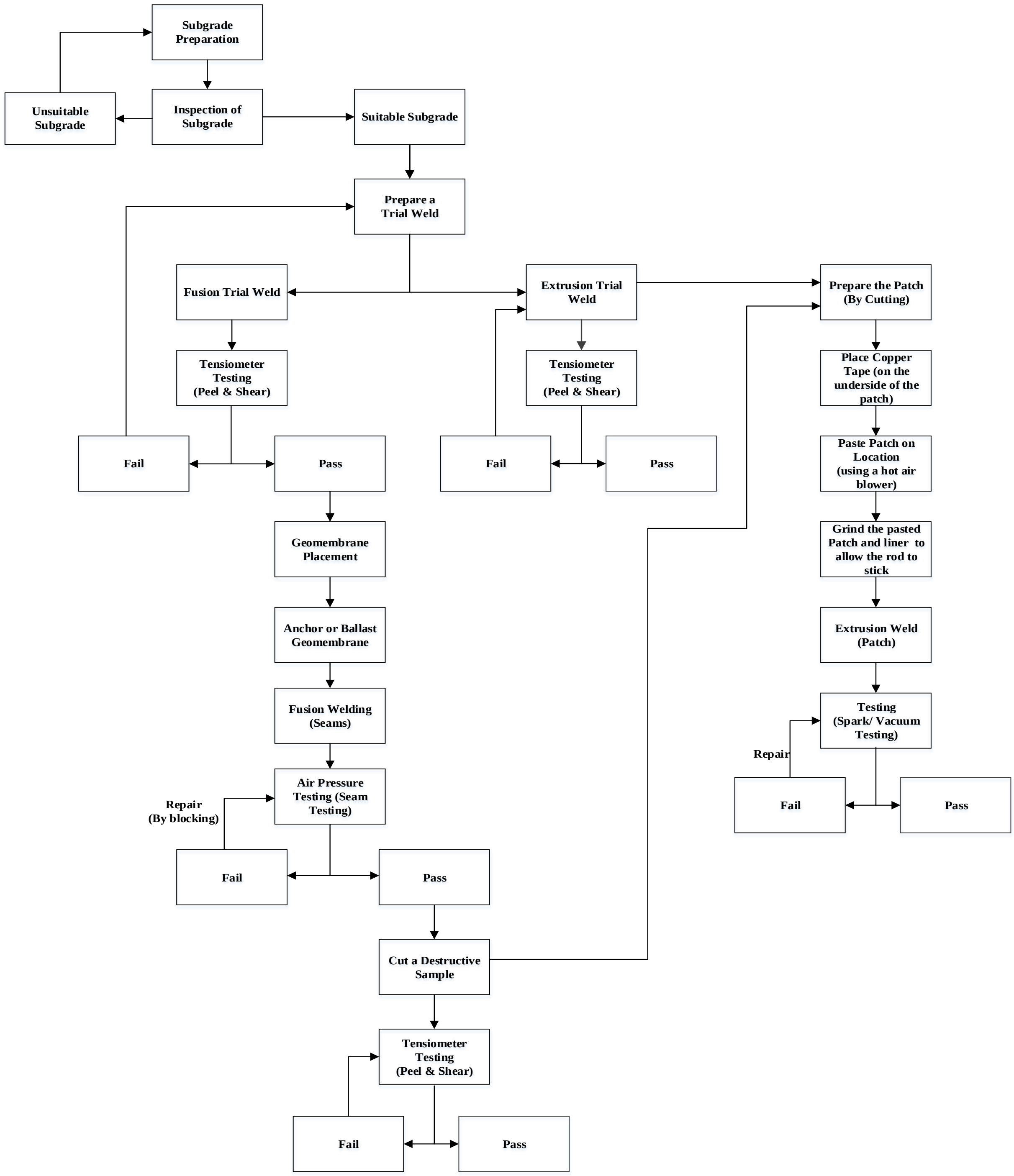

Figure 1. Liner Construction Sequencing

4 Unwritten rules

Practical knowledge gained from successful installations includes understanding site-specific challenges, optimizing material usage, and closely monitoring installation procedures. These unwritten rules guide practitioners in achieving excellence in liner construction and ensuring the long-term performance and effectiveness of HDPE geomembrane liners (Shackelford, Sevick, & Eykholt, 2010). Some unwritten rules (in terms of dos and don’ts) of mastering HDPE geomembrane liner construction include:

4.1 Dos

1. Always deploy in the direction of the wind. Wind can create challenges in managing large panels of HDPE, leading to potential damage or improper placement (see Figure 2). This helps minimize property damage or improper placement of liner.
2. Always ensure that there is adequate temporary anchoring and ballasting devices (commonly sandbags), to prevent uplift and damage due to winds.
3. Allow freshly deployed liners and those installed earlier (days older) to sit overnight. This allows the properties of the fresh liner to stabilize, making them more consistent with the properties of previously deployed sections. By doing so, this can reduce the occurrence of burnouts and mitigate tension-related issues, such as wrinkles, that arise when older sections of the liner exert stress on newly installed segments.
4. Standards (section 2) recommend adjusting the temperature of welding equipment every 4 to 8 hours. However, based on our on-site observations, we have noted significant temperature fluctuations within the first 4 to 5 hours of the day. Therefore, we recommend adopting the minimum standard of 4-hour intervals for temperature adjustments from the beginning of the day. This practice helps to reduce the number of burnouts and ensures consistent welding quality throughout the process.
5. During hot weather, HDPE liners can expand and become more flexible, making it challenging to maintain the desired shape and tension. To mitigate these issues, it is essential to ensure the welding equipment is adjusted to account for the higher ambient temperature, as excessive heat can cause burnouts at the seams. Reducing the welding temperature slightly and increasing the cooling time can prevent this issue.
6. In cold weather, HDPE liners become less flexible and more prone to contracting, which increases tension in the material (see Figure 3). To address this, adjust the welding equipment to a higher temperature setting to ensure proper seam bonding, as the colder environment can reduce the efficiency of the welding process.
7. Ensure that the overlap between liner sections is always oriented away from the deposition pipeline. This minimizes the potential for welding tears that can occur due to the pressure exerted by the deposited materials. By directing the overlap away from the source of pressure, the liner's seams are better protected from stress and strain, thereby enhancing the overall integrity and longevity of the liner system.
8. Troubleshoot the fusion liner welds before Non-Destructive Testing (NDT) them. This helps you identify where there could be a potential failure along a seam
9. Minimize the wall to basin liner bridge. Placing a breaker panel strategically helps alleviate liner tension from the wall to the TSF basin. Practical site observations have shown that keeping this distance within one to two meters from the toe of the wall effectively reduces tension, especially in cold weather conditions, thereby minimizing the risk of liner displacement. This approach addresses concerns such as liner trampolining, promoting greater durability and operational reliability of the TSF liner system.
10. Do consider cutting a section of the liner and creating a sump to remove and collect rainwater if testing is required after a rain event and the water depth on the liner is lower than what can be removed by pumping alone and if sweeping rainwater is an impossible task.
11. Following a rain event, water tends to accumulate on the prepared and compacted surface, taking longer to evaporate. Use a sump to promptly drain the water if the surface is urgently needed for deployment. After excavating the sump and draining the rainwater, remove the saturated material from the sump, then backfill it with fresh subgrade material and reprepare the surface to meet project specifications.
12. When blocking seams to perform NDT (Air pressure testing), always make sure that the bottom overlap of the seam is ground before blocking. This ensures that the seam is securely sealed and allows for accurate testing of its integrity under air pressure conditions.

4.2 Don’ts

1. Do not rely on spark testing extrusion welds on wet liners, as it is impossible to accurately detect sparks. Instead, use vacuum box testing to identify leakage points.
2. Do not perform spark tests on extrusion welds when the liner is wet, as it poses a significant health hazard due to the risk of electric shock or short circuits.
3. Avoid using a cap (small cut of liner used to repair large lengths of failed seams) smaller than 1 meter, as site observations have shown that it increases tension between the two liners joined by that cap, resulting in the formation of wrinkles.
4. Do not weld over wet or damp liner as this inhibits bonding.
5. Avoiding cleaning of welding rod before using it to weld which can lead to poor weld quality. Dust contamination of the welding machine can cause degradation of the performance of the welding machine and increased maintenance of it.
6. Do not extrude over fish mouths (T-liner joints), always go for patches instead. The point of interaction for those 3 seams has a bigger opening, so by installing a patch we are diverting the forces or pressure away from it.
7. Do not weld the liners together without cleaning it from dust or fines. Dust or fines can prevent proper fusion between the liner materials. This contamination may result in weak welds that are more susceptible to failure.

5 Challenges and solutions during liner construction

Challenges often encountered in liner construction include welding burnouts, seam failures caused by water during welding, contamination from dust, and insufficient surface preparation. Inadequate testing can also be a significant challenge in liner construction. Differential Settlement and Subgrade Instability can also pose challenges in liner construction. Here are some of the challenges experienced from on-site experience:

1. Welding a straight liner to a wrinkled liner presents several challenges that can lead to burnouts and the need for unnecessary patches (see Figure 4).
2. Fusion and Extrusion welding Burn outs due to improper temperature control and inconsistent welding speed. To address these issues, adjust the welding equipment to the right temperature in accordance with the weather condition and continuous testing through peel and shear tests on sample welds are recommended solutions (see Figure 5, Figure 6 and Figure 7).
3. Failures due to dust and water contamination. These hinder proper bonding during welding. To prevent this, maintain a clean work environment in welding areas and ensure thorough cleaning of liner surfaces before welding. Figure 8 shows a good fusion weld due to cleaning of liner surfaces before welding. To address seam failures in HDPE geomembrane liner construction, it is important to conduct peel and shear tests on sample welds to ensure proper bonding of the liner materials (see Figure 9).
4. Off seam weld. This weld will not pass an air pressure test. To avoid off seam weld failures, it is crucial to ensure proper alignment and overlap of liner panels before welding, as well as using appropriate welding techniques and inspections to detect any potential issues before they become larger problems.
5. Slag inclusions exists when the welding rod becomes trapped in the weld. To address this, it is crucial to maintain proper welding temperature, pressure, and speed, as well as conduct regular visual inspections and non-destructive testing to detect any issues and ensure proper fusion and integrity of the weld.
6. Differential settlement or subgrade instability. This can lead to stress and eventual failure of the liner. Poorly compacted subgrade increases the risks of settlement and liner damage. To address these issues, it is important to ensure proper compaction of the subgrade before liner installation, as well as consider using cushioning layers such as geotextiles to distribute stress evenly and protect the liner. Additionally, regular inspections during installation are essential for making necessary adjustments to maintain stability.
7. The trampolining effect caused by the liner being pulled tightly in the anchor trench, also caused by use of smaller caps and shorter distance of toe breaker panel distance. This tension can exacerbate settlement problems, increasing the likelihood of liner damage over time. When the liner is exposed to cooler temperatures, it contracts and becomes less taut, reducing the risk of excessive tension and trampolining when backfilled. By timing the backfilling process to coincide with cooler temperatures, the liner is in a more relaxed state, allowing it to conform more easily to the anchor trench without being stretched tightly. This reduces the likelihood of trampolining and minimizes stress on the liner.
8. Equipment breakdown due to dust (when fine particulate matter accumulates on machinery components, interfering with their functionality and causing mechanical failures or malfunctions, ultimately leading to downtime and productivity losses). Minimize welding during harsh winds.

Figure 2. Wind beneath the liner caused by insufficient anchoring.

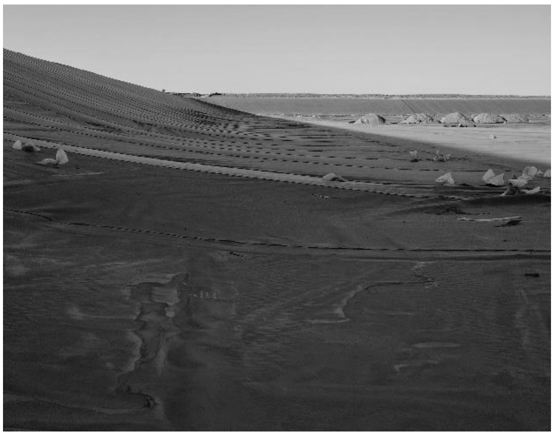

Figure 3. A trampolining effect of a liner at the upstream toe of the wall.

Figure 4. A burn out due to welding a straight liner to a wrinkled liner.

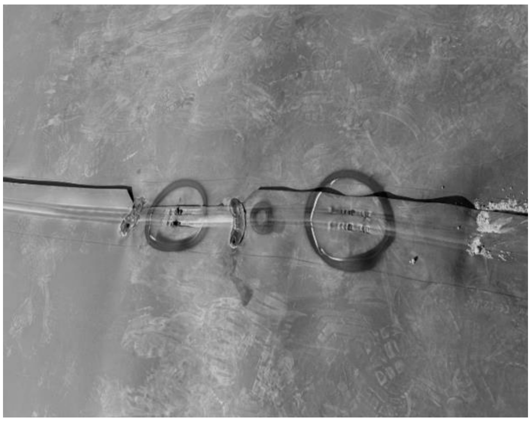

Figure 5. Burn out due to improper temperature control and inconsistent welding speed (fusion welding).

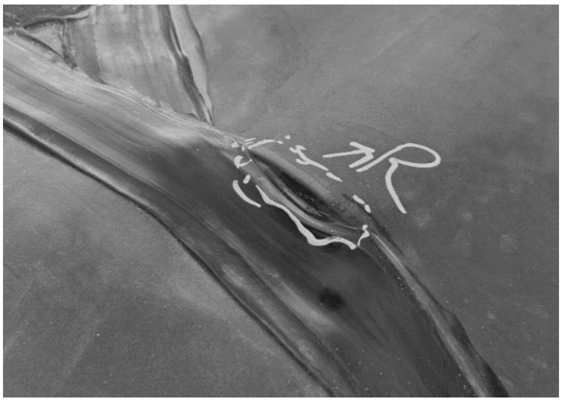

Figure 6. Burn out due to improper temperature control and inconsistent welding speed (extrusion welding)

Figure 7. Burn out due to placing an extrusion gun groove on a liner for a long time while machine is on.

Figure 8. A destructive sample a peel test (Pass)

Figure 9. A cut out seam sample after a seam was failing NDT

6 Conclusion

This paper has covered the fundamental aspects of HDPE liner construction, emphasizing the importance of regulatory compliance and the essential practices for quality control and assurance. Adhering to these standards and implementing best practices allows professionals to significantly reduce the risks associated with TSF operations, such as potential environmental pollution and compromised water resources. Practical insights into the "do's and don'ts" of liner construction, along with strategies to overcome common challenges, serve as valuable resources for those involved in these projects. These guidelines and recommendations are designed to enhance the performance and longevity of HDPE geomembrane liners, ensuring safer and more reliable containment of tailings. Ultimately, a thorough understanding and diligent application of these principles will enable professionals to master the art of liner construction, contributing to sustainable and safe mining operations.

7 References

ASTM D 1204. (2020). *Standard Test Method for Linear Dimensional Changes of Non Rigid Thermoplastic Sheeting or Film at Elevated Temperature.*

ASTM D 1238. (2013). *Standard Test Method for Flow Rates of Thermoplastics by Extrusion Plastometer.*

ASTM D 1505. (2018). *Standard Test Method for Density of Plastics by Density Gradient Technique.*

ASTM D 4437-08. (2023). *Standard Practice for Non-destructive Testing (NDT) for Determining the Integrity of Seams Used in Joining Flexible Polymeric Sheet Geomembranes.*

ASTM D 4439. (2023). *Terminology for Geosynthetics.*

ASTM D 4833. (2020). *Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products.*

ASTM D 5199. (2019). *Standard Test Method for Measuring Nominal Thickness of Smooth Geomembranes.*

ASTM D 5397. (2020). *Standard Test Method for Evaluation of Stress Crack, Resistance of Polyolefins using Notched Constant Tensile Load Test.*

ASTM D 5641. (2011). *Standard Practice for Geomembrane Seam Evaluation by Vacuum Chamber.*

ASTM D 5820. (2023). *Pressurized Air Channel Test for Dual Seamed Geomembranes.*

ASTM D 5820-95. (2018). *Test Method for Air Testing.*

ASTM D 5994. (2021). *Standard Test Method for Measuring Nominal Thickness of Textured Geomembranes.*

ASTM D 6365. (2018). *Standard Practice for the Nondestructive Testing of Geomembrane Seams using The Spark Test.*

ASTM D 638. (2022). *Standard Test Method for Tensile Properties of Plastics.*

ASTM D 7002. (2022). *Standard Practice for Electrical Leak Location on Exposed Geomembranes Using the Water Puddle Method.*

ASTM D 7007-15. (2015). *Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials.*

ASTM D 751. (2019). *Standard Test Methods for Coated Fabrics.*

ASTM D 792. (2020). *Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.*

Baker, G. L., Vogel, E. R., & Smith, M. R. (2008). *Glass Transitions in Polylactides.* Taylor & Francis.

Derradji, M., Mehelli, O., Liu, W., & Fantuzzi, N. (2021). Sustainable and Ecofriendly Chemical Design of High Performance Bio-Based Thermosets for Advanced Applications. (p. 9). Frontiers Media.

GISTM. (2020). *Global Industry Standard om Tailings Management.*

GRI GM 10. (2021). *The Stress Crack Resistance of HDPE Geomembrane Sheet. Revision 5.*

GRI GM 13. (2021). *Test Properties, Testing Frequency for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes. Revision 16c.*

GRI GM 14. (2013). *Guide for Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes. Revision 1.*

GRI GM 17. (2021). *Test Methods, Test Properties and Testing Frequency for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes. Revision 14.*

GRI GM 9. (2013). *Cold Weather Seaming of Geomembranes. Revsion 1.*

GRI GM19a. (2021). *Seam Strength and Related Properties of Thermally Bonded Homogeneous Polyolefin Geomembranes/Barriers. Revision 10.*

GRI GM20. (2003). *Guide for Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using Control Charts.*

International Association of Geosynthetic Installers. (2019). *Guidelines for Installation of HDPE and LLDPE Geomembrane Installation Specification.* IAGI.

Koerner., R. M. (2012). *Designing with Geosynthetics. 6th Edition.*

Ratnayake, R. M., & Vik, K. (2012). Weld integrity assurance: a case study for prioritising welding quality deterioration factors in piping components fabrication. http://doi.org/10.1504/ijcsyse.2012.050235.

Rowe, R. (2007). Advances and Remaining Challenges for Geosynthetics in Geoenvironmental Engineering Applications. 30(1), 3-30: hhttps://doi.org/1061/(asce)gt.1943-5606.0002239.

SANS 10409. (2020). *Design, selection and installation of geomembranes. Edition 2.*

Shackelford, C. D., Sevick, G. W., & Eykholt, G. R. (2010). Hydraulic conductivity of geosynthetic clay liners to tailings impoundment solutions. Elsevier BV. 28(2), 149-162. https://doi.org/10.1016/j.geotexmem.2009.10.005.

South Africa Government. (2008). *National Environmental Management Act. (Act 59 of 1998).*

Tuomela, A., Ronkanen, A., Rossi, P. M., Rauhala, A., Haapasalo, H., & & Kujala, K. (2021). *Using Geomembrane Liners to Reduce seepage through the Base of Tailings Ponds - A Review and a Framework for Design Guidelines.* Multidisciplinary Digital Publishing Institute.