WHITEPAPER:

TRANSFORMING MINE CLOSURE WITH GEOSYNTHETICS

STRATEGIES FOR LONG-TERM ENVIRONMENTAL PROTECTION

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1.0 EXECUTIVE SUMMARY

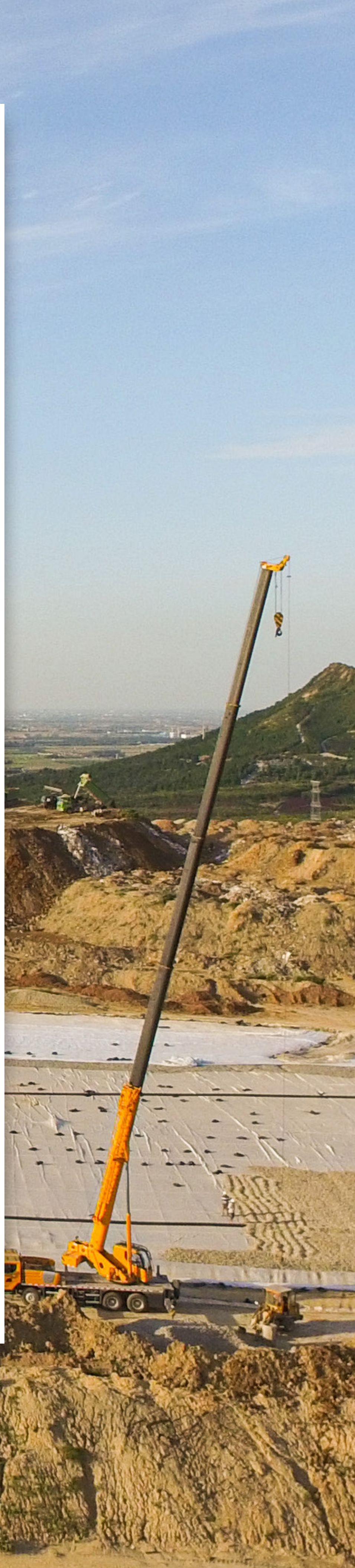
A mine has a finite lifespan which is dependent on the volume of resources available to be extracted or is dictated by the economic viability of continuing to extract those resources. Once the mine operation has ceased, the next stage in the mine's lifecycle, is mine closure.

Mine closure is a significant industry challenge that involves the asset owner, the local community and government agencies that requires significant financial provision in order to address safety, environmental and social risks linked to the mine operation (ICMM).

A recent report by CSIRO (November 2023) estimates that approximately 240 mines will close by 2040, with over 2,220 active mines, and tens of thousands of mines awaiting rehabilitation across Australia. Expenditure on mine rehabilitation and closure is projected to exceed $4 billion each year.

The modern day mine must operate daily with rehabilitation and closure in mind, which has a two-fold benefit of meeting ongoing environmental obligations, while also reducing lump costs when operations cease. This paper is specifically focuses on the benefits of incorporating geosynthetic solutions into mine closure activities.

Contents



2.0 INTRODUCTION

Mine rehabilitation presents a complex array of challenges, reflecting the environmental, technical, social, and economic impacts of mining activities. One of the most pressing issues is environmental contamination, which arises from the release of pollutants such as heavy metals, acids, and other hazardous substances into soil and water systems. Acid mine drainage (AMD) poses a particularly severe threat, as it can harm aquatic ecosystems and contaminate local water sources. Additionally, air quality may deteriorate due to dust and emissions, further complicating rehabilitation efforts.

Erosion and sedimentation exacerbate these challenges, with the removal of vegetation and topsoil leaving the land vulnerable to severe erosion. This leads to increased sediment runoff, negatively impacting nearby water bodies and disrupting aquatic ecosystems. Simultaneously, habitat destruction and biodiversity loss are significant concerns. Mining activities often devastate native ecosystems, making it challenging to restore the land to its original state or develop sustainable alternatives that support flora and fauna.

Water management is another critical issue, as mines frequently disrupt natural hydrological systems. The formation of AMD, combined with the need to manage water usage in resource-scarce regions, poses substantial difficulties for operators. Meanwhile, the containment of tailings and waste materials requires robust engineering solutions to prevent leaks, spills, and structural failures. Without effective waste management, these materials can migrate into surrounding environments, causing long-term harm.

Rehabilitating mined land also involves addressing land stability issues, including slope failures and landslides, which pose risks to infrastructure and ecosystems. The financial burden of rehabilitation adds another layer of complexity, as the significant costs associated with restoring mine sites can strain budgets and require substantial financial assurances.

Beyond the technical and financial considerations, rehabilitation efforts must navigate regulatory and compliance challenges, meeting stringent environmental standards and often complex permitting processes. Stakeholder engagement is equally vital, as local communities must be involved in the planning and execution of rehabilitation projects to address their concerns and support economic transitions. Furthermore, climate change introduces additional uncertainty, necessitating adaptable and resilient rehabilitation strategies to cope with extreme weather events and shifting environmental conditions.

Together, these challenges underscore the need for innovative, sustainable, and well-coordinated approaches to mine rehabilitation. Emerging technologies, such as geosynthetic materials, offer promising solutions to many of these issues by enhancing stability, minimising environmental impact, and reducing long-term costs.

Sustainable solutions are crucial in mine rehabilitation to ensure that environmental, social, and economic impacts are effectively managed and that mined lands can support ecosystems and communities long into the future. These practices not only help in restoring the land to its original condition or repurposing it for new uses like agriculture or recreation but also align with the United Nations' Sustainable Development Goals (SDGs). Specifically, SDG 15 (Life on Land) aims to combat desertification, halt and reverse land degradation, and halt biodiversity loss, which directly ties into mine rehabilitation efforts. Furthermore, SDG 6 (Clean Water and Sanitation) is addressed through careful management of water resources post-mining. Sustainable practices, such as the use of innovative materials like geosynthetics, not only enhance the effectiveness of rehabilitation but also reduce long-term costs and environmental footprints.

3.0 OVERVIEW OF GEOSYNTHETIC MATERIALS

3.1 Geosynthetics and their Functions

The official definition of a geosynthetic material (according to ASTM D4439) is 'a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a human-made project, structure, or system'. Geosynthetic products are typically delivered in a rolled up format that are several metres in width, by tens or hundreds of metres in length, and can be sewn, welded or glued together to cover areas spanning tens of hectares.

The main types of geosynthetics can be grouped into the following categories; geotextiles, geomembranes, geosynthetic clay liners, geogrids, geonets, geocomposites and geocells. There are other smaller volume types such as geofoams and geopipes. These types of geosynthetics serve one or more functions, and the main functions can be grouped into uses for; barrier, drainage, filtration, protection, reinforcement, stabilisation, separation and erosion control. The following table highlights the geosynthetic types and the functions they can fulfil.

GEOSYNTHETIC TYPE	Barrier	Drainage	Filtration	Protection	Reinforcement	Stabilisation	Separation	Erosion Control
Geotextile		✔	✔	✔	✔		✔	✔
Geogrid					✔	✔		
Geonet		✔						
Geomembrane	✔							
Geosynthetic Clay Liner	✔							
Geocomposite		✔	✔		✔		✔	
Geocell				✔		✔		

3.2 Key Properties and Advantages

Geotextiles are made up of synthetic fibres (typically polypropylene, polyester or polyethylene) for mid to longer term applications, or can consist of natural fibres (jute, coir, hemp) for shorter temporary applications, such as erosion control applications until natural vegetation is established. In more recent years it is now possible to produce geotextiles from bio-based sources such as PLA (polylactic acid) which is derived from cornstarch or sugar cane. Fibres are formed into a geotextile by differing processes that of which can dictate the final properties of the material – the processes include, needle punching (non-wovens), weaving (wovens), spinning, knitting, heat setting or a combination. The main property of a geotextile is that is it porous, allowing liquid to flow through it (perpendicular or normal to the plane), while enabling separation and filtration between dissimilar soils.

Geomembranes are thin (on the order of a few millimetres) impervious sheets used for lining and/or capping facilities storing liquids or solids (waste rock dumps, tailings storage facilities (TSFs), process liquids and evaporation ponds, etc). They can be unreinforced or reinforced with internal scrims or geotextiles and are made with many different polymers or modified bitumen. The application in question can dictate the type of polymer required, whether it be exposure to extremes of pH, saline liquids, or hydrocarbons, and whether buried or exposed to UV – there are a multitude of solutions on the market that need to be qualified so that the liner design life is not compromised.

Geosynthetic clay liners (GCL) are a composite of high-quality bentonite clay that is sandwiched between geotextiles, which is typically needle punched together to result in a high internal shear strength, low permeability barrier. The bentonite clay can be modified with select polymers to give a GCL a wider range of chemical compatibility in challenging environments. GCLs are used in composite action with geomembranes which synergistically work together to give greater barrier benefit, however they can also be used as a single liner in environmental containment applications when designed for accordingly. The advantage of a GCL is that they can replace a traditional 900 mm thick compacted clay liner (CCL) which has numerous technical and economic benefits.

Geogrids are constructed with an array of polymers and have large open apertures so that they can interact with the surrounding soil or aggregate materials. They can be manufactured in various ways including; punching and stretching, weaving or knitting, or bonding straps together. There are a wide range of applications from stabilisation of aggregate material in a road base or haul road, though to reinforcement of slopes and construction of mechanically stabilised earth walls. Their advantage is that they can reduce the volume of natural quarried materials required, or structures can be built that may not traditionally be possible with poorer quality fill materials.

Geonets and geocomposites are almost exclusively used in drainage applications, and the core geonet is produced by extrusion of polymer (typically HDPE) ribs into a 3D structure allowing for void channels for passage of liquid or gas through the plane of the product. Geotextiles can be bonded to one or both surfaces, to form a geocomposite that can serve a filtration function and preventing fines from clogging the central drainage core. Geonets and geocomposites that are less than 10 mm in thickness can replace much thicker layers of drainage aggregate.

Geocells, a cellular confinement system, is a three-dimensional honeycomb structure made from materials including HDPE, used to stabilise soil, reduce erosion, and enhance load-bearing capacity in construction. These interconnected cells are expanded on-site, filled with soil, gravel, or other materials, and provide confinement that improves the structural integrity of slopes, road bases, retaining walls, and more. They are valued for their durability, environmental benefits, and the significant reduction in the amount of infill required, making them cost-effective for numerous applications in civil engineering.

3.3 Applications Across Industries

Geosynthetics find extensive use across a multitude of industries due to their adaptability in soil stabilisation, erosion control, and fluid/solid containment. In civil engineering, they're widely used for road construction, reinforcing embankments, and improving subgrades, as well as in the building of retaining walls, bridge abutments, and tunnels. The environmental protection sector utilises geosynthetics in landfills for lining, capping, and leachate management to safeguard against soil and groundwater contamination, and in the remediation of polluted sites.

In mining, geosynthetics line heap leach pads, tailings dams, and manage mine waste to prevent environmental degradation, while also aiding in soil stabilisation. In agriculture, geosynthetics are used for pond and canal linings, drainage, and erosion control. Water management relies on them for controlling seepage and evaporation, managing water flow in reservoirs, canals, and dams, and preventing erosion. Transportation infrastructure, including roads, railways, airports, and ports, uses geosynthetics for soil reinforcement, stabilisation and bearing capacity improvement.

In coastal and river engineering, geosynthetics help with bank stabilisation, erosion control, and the construction of breakwaters and artificial reefs. Aquaculture employs them for lining ponds to prevent water loss. In industrial settings like chemical, oil, and gas, geosynthetics serve in secondary containment systems to avert environmental contamination from spills, but also help build access in remote, difficult to construct areas, showcasing their broad utility and economic and environmental advantages.

4.0 APPLICATIONS OF GEOSYNTHETICS IN MINE REHABILITATION

Traditional mine process rehabilitation planning and associated costs to a site once operations have ceased. This has led to a numerous legacy sites that remain unrehabilitated, resulting in large lump sum costs for the mining company who is intent on implementing best practice once production has ceased.

The modern day mine must operate daily with rehabilitation and closure in mind, which has a two-fold benefit of meeting ongoing environmental obligations, while also reducing lump costs at the closure stage.

The incorporation of geosynthetics into mine rehabilitation represents a transformative approach to addressing the environmental and engineering challenges associated with restoring mined lands. These advanced materials offer versatile and cost-effective solutions for erosion control, waste containment, water management, and land stabilisation. By leveraging the unique properties of geosynthetics—such as their durability, permeability/impermeability, and adaptability—mine operators can achieve sustainable rehabilitation outcomes that align with environmental regulations and community expectations. From stabilising slopes to improving soil quality for revegetation, geosynthetics enhance the efficiency and longevity of rehabilitation projects, ensuring that post-mining landscapes are safe, resilient, and conducive to ecological restoration.

4.1 Erosion and Sediment Control

Mine site surface remediation and revegetation is an integral component of operations from exploration to mine closure. There is a need to minimise and mitigate the environmental effects of vegetation clearance and potential for sediment movement through wind and water erosion. The visual perception of dust generation and water erosion presents a clear challenge to the environmental requirements of a site, and does not present a visual perception of a site that is well managed environmentally with progressive rehabilitation in mind. There is also a fundamental cost benefit in addressing surface erosion immediately in localised areas, rather than having to deal with large scale erosion which has been ignored over a number of years.

Erosion and sediment control are critical components of mine site rehabilitation, as exposed soil surfaces and disturbed landscapes are highly vulnerable to degradation. Geosynthetic materials, such as geotextiles and geocells, provide effective solutions to mitigate these issues. Geotextiles act as protective barriers, stabilising soil and reducing surface runoff, while geocells create a cellular confinement system that prevents soil displacement on steep slopes and facilitates vegetation growth. Additionally, geosynthetic erosion control blankets can enhance seed germination and anchor vegetation, providing long-term soil stabilisation. These materials minimise sediment runoff into nearby water bodies, preserving aquatic ecosystems, and also reduce the need for frequent maintenance, making them a sustainable and cost-effective choice for mine rehabilitation.

4.2 Drainage, Dewatering and Water Management

Drainage of stormwater is critical to protect areas of rehabilitation on a mine site, particularly during periods of early establishment of revegetation. Geosynthetic drainage systems are utilised to restrict water entering rehabilitated waste and tailings storages, ensuring rain events do not compromise rehabilitated landforms, and manage runoff volumes leaving the site footprint.

Options include silt fences and surface erosion treatments to prevent surface sediment loss, traditional “roadside drains” to divert stormwater around infrastructure, open channel drains that are geotextiles beneath rock for larger volumes, progressing to synthetic erosion control options and then high velocity use of gabions and reno mattresses for river training. Each solution requires careful analysis in regard to drainage volumes and velocities.

Geotubes are a geosynthetic solution to aid dewatering activities. The primary aim when considering the rehabilitation of waste and sludge storage is to restrict the amount of water relative to solids in the slurry to be contained. High water content increases the volumes of contaminant to be contained, but also presents geotechnical stability challenges when attempting to rehabilitate. Geotube dewatering containers are used to increase solids content of sludge to be contained which makes it easier to rehabilitate, but can also polish water sufficiently for use to positively achieve revegetation release into the environment.

Geotube containers use a highly engineered woven textile designed for dewatering high moisture content sludge and sediment. They are available in many sizes, depending on the volume and deployment space requirements and have a demonstrated history for dewatering tailings, sediment ponds and critical applications.

Wick drains, or prefabricated vertical drains (PVDs), are designed to speed up the consolidation of compressible soils by providing shorter flow paths for water contained in the soil. As the soil consolidates its strength improves which will allow higher loading from larger stockpiles. The use of wick drains can reduce consolidation times from years to months and facilitate more rapid access to sludge sites that require rehabilitation.

4.3 Tailings Containment, Waste Rock Capping Systems, and Capping over Tailings and Open Pits

Mining companies must now demonstrate processes that meet an increasingly critical public perception in regard to their social and environmental licences to operate.

The incorporation of high-end engineered geosynthetics in the lining and capping of mine waste and tailings, is seen as the optimum solution to mitigate groundwater contamination. The key advantage of geosynthetic liners for closure is that they exhibit consistent hydraulic performance across the footprint when compared to soil liners, and can be designed and tested with extended longevity to work in conjunction with the revegetated landform. The suitability of the geosynthetics should be vigorously analysed in the laboratory, to ensure their compatibility with any waste chemistry in contact, and that they can survive the settlement stresses long term.

The choice of capping system must demonstrate site longevity, and will depend on the liquor chemistry, rainfall and exposure conditions, as well as the site stresses and properties of surrounding soils. The first lining option reviewed is generally a polymeric geomembrane and there are a range of options to suit site conditions. A geosynthetic clay liner can be used as a composite layer or as a standalone option if conditions allow. For specific function, the option of a bituminous geomembrane could be utilised but for each option it is critical that site performance criteria are established. A geocomposite or geopipe system can also be utilised above the liner to remove stormwater and resulting hydraulic head pressure from above the lining system in areas of high rainfall.

The first challenge in remediation of mine waste storages is often based around access to the site to construct the capping layer. Design strategies are available that enable the use of high strength geotextiles or geogrids to enable cap access and create a bearing capacity that can be trafficked with construction plant. Unlike civil engineering solutions, the liquor chemistry must be considered in terms of geosynthetic performance, as stress-strain behaviour will change if the polymer is impacted by acid or high pH environments.

High strength geotextiles can be laid directly on the tailings or sludge to increase the shear strength of the fill material and see an increase in foundation bearing capacity. This enables rapid site access and construction, ordinarily only achieved through high volumes of imported soil, left to consolidate over an extended period.

The geotextile both separates introduced material and provides a reinforcement function, so understanding the soil parameters and installation method onsite is critical to correct geotextile selection. For critical tailings applications, design must consider the polymer utilised to manufacture the product, which will see loss of tensile performance if incompatible to site chemistry.

Geogrids can be utilised for mechanically stabilising soils available for capping construction, which results in a positive shear response through the capping depth and a structurally superior formation for construction traffic. To achieve maximum benefit, the choice of geogrid must be designed and link to the construction process and load conditions. The net result is a site-specific cost saving by implementing a thinner soil layer that achieves increased bearing capacity and stability under load.

Geocells can be laid above a separation geotextile on the tailings surface and infilled to provide a thin soil layer that provides maximum bearing capacity for construction traffic. The structure distributes surface stresses effectively to prevent soil shear failures, whilst also allowing a thin pavement construction to maximise soil performance under construction loads.

4.4 Slope Stabilisation and Bridging of Old Workings

A clear safety issue of legacy mine sites that remain unrehabilitated are both the legacy risk of open pits that contain contaminants, but there are often old workings in the form of open shafts, open pits and other associated infrastructure that present significant risk to the general public who will have access to the site.

High strength geotextiles can be laid directly over voids that are filled with low bearing capacity soils to create a reinforcement function and render the mine void safe for any traffic that crosses the legacy site. The design alternative is ordinarily only achieved through high volumes of imported soil to fill a void, with prescribed plant to construct, prescribed design criteria to be met, left to consolidate over an extended period.

The geotextile separates introduced material and provides a reinforcement function, so understanding the soil parameters, and installation method onsite is critical to selecting the correct geotextile.

4.5 Final Rehabilitation and Revegetation Support

Geosynthetics play a vital role in the final rehabilitation and revegetation of a closed mine by addressing challenges such as soil stability, moisture retention, and erosion control.

Geosynthetics enhance soil quality for vegetation growth by improving stability, drainage, nutrient retention, and erosion control, creating an environment conducive to sustainable revegetation. Materials like geotextiles and geocells provide reinforcement to weak soils, preventing compaction and enabling root systems to establish more effectively. By stabilising the soil structure, geosynthetics reduce surface runoff, allowing water and nutrients to remain in the growth zone, which is crucial for plant development.

Geosynthetic drainage layers, such as geocomposites, help regulate moisture levels by directing excess water away from the root zone while retaining adequate hydration for plants. This is particularly beneficial in areas with uneven water distribution or poorly draining soils. Additionally, geosynthetics can isolate contaminated or nutrient-poor substrates by acting as a barrier, enabling the placement of clean growth media over degraded soil. Erosion control mats and blankets further enhance soil quality by protecting seeds and young plants from being washed away, ensuring successful germination and growth. Through these combined benefits, geosynthetics create a stable, nutrient-rich, and moisture-optimised environment that accelerates vegetation establishment and supports long-term ecological restoration.

By providing long-term stability and enhancing the effectiveness of restoration efforts, geosynthetics contribute to the recovery of ecosystems impacted by human activities, helping to restore biodiversity, improve soil health, and create self-sustaining landscapes.

TAILINGS CAPPING

Solmax Mirafi PET geotextile
Solmax Mirafi RSi geotextile
Solmax Mirafi H2Rx geotextile

SLOPE PROTECTION

Jute Mat
Grassroots

TAILINGS CONTAINMENT

Atarfil HD geomembrane
Bidim C conductive geotextile
Flownet geocomposite

DEWATERING

Solmax Geotube

REVEGETATION

Jute Mat
Grassroots
Presto Geoweb geocell

UNSEALED HAUL ROADS

Solmax Mirafi RSi geotextile
Tensar InterAx geogrid
Bidim Green geotextile
Presto Geoweb geocell

MINE LANDFILL AREA

Flownet geocomposite
Sorbseal hybrid geosynthetic clay liner
Atarfil HD geomembrane
Bidim C conductive geotextile

DAM LINING

Bidim C geotextile
Atarfil HD geomembrane

REINFORCEMENT

Maccaferri Paragrid geogrid
Maccaferri Green Terramesh wire mesh
Maccaferri Gabion basket

5.0 ENVIRONMENTAL AND ECONOMIC BENEFITS

Geosynthetics provide a significant reduction in environmental footprint in various applications, including mine rehabilitation and ecosystem restoration. These products are engineered to improve efficiency, reduce resource consumption, and mitigate environmental impacts compared to traditional construction methods. GRI White Paper #41 highlights how various applications can be decarbonised with geosynthetic solutions, and extract Table 4 below shows that on average, across all applications 65% carbon savings are measured.

Application Area	No. Cases Described	Average Carbon Savings
Walls	6	69%
Embankments and Slopes	4	65%
Armoring	4	76%
Landfill Covers	3	75%
Landfill Liners	2	30%
Retention	3	61%
Drainage Pipe	3	40%
TOTALS	**25**	**65%**

Table 4 – Case Studies from GRI-24 Conference (March, 2011)

Bulk materials like concrete, rock, and gravel can be replaced or supplemented, reducing the need for extraction, transport, and processing of natural resources. For example, geogrids can reinforce or stabilise soils, enabling the use of local materials instead of importing large quantities of fill. Geocomposites can replace or supplement thick aggregate drainage channels or layers, again reducing truck movements and quarrying of large quantities of natural resources. Geomembranes and geosynthetic clay liners can replace a 1 m thick layer of good quality compacted clay as an effective barrier, which is not always readily available. Geotextiles can function as effective filters and replace engineered rock/soil filter systems.

Energy and embodied carbon reduction of a project can be realised due to the lightweight nature of geosynthetics which lowers transportation and installation energy requirements compared to heavier, conventional materials. Additionally, geosynthetics contribute to long-lasting infrastructure, reducing the need for frequent maintenance and reconstruction, which saves energy over time.

Water management can be improved with materials such as geomembranes and geotextiles that help conserve water by preventing seepage and managing moisture levels in rehabilitation projects. The use of water to condition a soil for optimum engineering conditions can be significant when construction a 1 m thick compacted clay layer, the use of a geomembrane or GCL does not depend on as much water usage to provide the same or better barrier function. This efficient water management minimises water waste and reduces environmental strain in arid or water-stressed regions.

By containing contaminants and isolating polluted soils, geosynthetic barriers enable pollution control and prevent leaching into surrounding ecosystems, safeguarding water quality and reducing the environmental impact of rehabilitation activities.

Supporting vegetation and biodiversity can be achieved by stabilising soils, retaining moisture, and preventing erosion. Geosynthetics facilitate successful revegetation, which contributes to carbon sequestration and restoration of ecological functions.

The use of geosynthetics aligns with sustainable development principles by conserving resources, reducing emissions, and enabling effective environmental management. Their application in rehabilitation projects supports long-term ecological restoration with a smaller environmental footprint than traditional methods. In fact, geosynthetics align closely with the United Nations Sustainable Development Goals (SDGs) and play a critical role in advancing sustainable mine rehabilitation practices. By addressing key challenges such as soil stabilisation, water management, and ecosystem restoration, geosynthetics help transform degraded mining landscapes into sustainable, functional environments.

Their integration into mine rehabilitation strategies directly supports SDG 15 (Life on Land) by enabling biodiversity conservation and ecosystem recovery. Through the stabilisation of soils, erosion control, and support for vegetation growth, geosynthetics provide a strong foundation for restoring natural habitats and ensuring long-term ecological health.

In addition, geosynthetics contribute to SDG 6 (Clean Water and Sanitation) by managing water quality in mine rehabilitation. Materials such as geomembranes and geotextiles are used to contain contaminants, prevent leachate migration, and protect nearby water bodies from pollution. These materials also facilitate the reclamation of wetlands and the restoration of hydrological systems, ensuring that rehabilitated sites can support clean water ecosystems. By enabling sustainable water management practices, geosynthetics play a vital role in maintaining water security during and after mine closure.

The use of geosynthetics also aligns with SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) by reducing the reliance on traditional construction materials, optimising resource efficiency, and minimising greenhouse gas emissions. Their lightweight nature and durability reduce transportation costs and energy use, while their ability to support revegetation enhances soil carbon sequestration. Moreover, geosynthetics improve the resilience of rehabilitated sites to climate-related challenges, such as extreme weather events and soil erosion, contributing to climate adaptation goals.

By leveraging innovative solutions and promoting collaboration among stakeholders, the integration of geosynthetics into mine rehabilitation not only accelerates the restoration of mined lands but also helps meet global sustainability targets. Their effectiveness in reducing environmental impact and fostering ecosystem recovery positions geosynthetics as a key tool for sustainable mine closure and long-term environmental stewardship.

Detail from GRI White Paper #41 in terms of economics clearly highlight there is also economic advantages of leveraging geosynthetic solutions when compared to traditional solutions, and this also translates to mine rehabilitation applications.

The environmental benefit of a geosynthetic product can be evaluated and captured in a Life Cycle Assessment (LCA). The LCA of a geosynthetic product evaluates its environmental impacts at each stage of its life, from raw material extraction to end-of-life disposal. This comprehensive approach helps to understand the sustainability benefits of geosynthetics compared to traditional construction materials.

By assessing the full life cycle of geosynthetics, it becomes clear that their environmental impacts are generally lower than those of traditional alternatives, particularly in applications such as erosion control, soil stabilisation, and water management. As the industry adopts innovative recycling processes and bio-based polymers, the sustainability benefits of geosynthetics are expected to improve further.

6.0 CHALLENGES AND CONSIDERATIONS

The use of geosynthetics in mining applications presents several durability and degradation concerns due to the harsh environmental conditions and chemical exposures typically encountered in mining operations. Key issues include durability concerns such as mechanical damage, high stresses and elevated temperatures.

During installation, geosynthetics can be subjected to punctures, tears, or other mechanical damages from sharp rocks or heavy equipment. This risk is heightened in mining where the ground can be less controlled over large footprints.

Mining operations often involve high load-bearing requirements, particularly under tailings dams or heap leach pads where the weight can exceed typical design specifications. Geosynthetics must withstand both static and dynamic loads without significant deformation or failure.

Mining sites, especially those in remote areas, can experience extreme temperature fluctuations. These can affect the flexibility and integrity of geosynthetic materials, like geomembranes, which might become brittle under cold conditions or degrade faster in heat.

There are further concerns with the use of polymeric materials and the potential for degradation due to exposure to harsh chemistries typically encountered in mine operations. Mining involves the use of aggressive chemicals for ore processing. Geosynthetics, particularly geomembranes and geosynthetic clay liners (GCLs), must be resistant to these chemicals. For instance, acid mine drainage (AMD) or alkaline solutions in bauxite refineries for example can lead to chemical degradation or leaching of antioxidants, reducing the material's lifespan.

Polyolefin materials (polypropylene, polyethylene) are susceptible to oxidative degradation: exposure to oxygen, especially in combination with high temperatures, can lead to oxidative degradation of polymers used in geosynthetics. Antioxidants are added to slow this process, but their depletion over time can lead to brittleness and loss of performance.

Although less of an issue when geosynthetics are buried, during installation or in exposed applications, UV radiation can degrade polymers. This is mitigated by adding UV stabilisers, but long-term exposure still poses risks.

For certain polymer types like polyester, the presence of water can lead to hydrolysis, which breaks down the polymer chains over time. This is particularly relevant in wet mining environments where geosynthetics are continually in contact with moisture, and more so in a higher pH environment.

The interaction of chemicals with geosynthetics under stress can lead to environmental stress cracking (particularly with HDPE), where the material fails at stresses lower than its tensile strength due to chemical exposure.

Predicting the service life of geosynthetics in mining is complex due to the synergy of multiple degradation mechanisms. Laboratory tests often use accelerated aging to estimate in-field durability, but translating these to real-world conditions can be challenging and require specific expertise.

While geosynthetics are designed for durability, the mining industry's unique conditions require careful selection, design, testing (with site specific conditions) and monitoring to ensure that these materials perform adequately over their intended service life. Regular inspections and conservative design practices are essential to manage these degradation risks.

In mine rehabilitation, geosynthetics face numerous design and installation challenges due to the harsh environmental and geotechnical conditions typical of mining sites. The materials must withstand extreme weather, UV radiation, and chemical exposure, necessitating thorough testing for compatibility and durability.

Soil variability and slope stability pose significant issues, requiring geosynthetics like geomembranes, geogrids, or geocells to be designed for specific soil conditions and dynamic loads. Installation is complicated by site inaccessibility, demanding stringent quality control to prevent damage during placement and ensure proper material integration.

Long-term performance is critical, especially for containment applications where preventing leakage is paramount. Furthermore, adherence to diverse regulatory standards across regions adds complexity, while the selection of cost-effective yet robust materials must balance initial expenses against long-term lifecycle costs, ensuring both environmental compliance and economic viability in rehabilitation efforts.

7.0 FUTURE TRENDS AND INNOVATIONS

Advances in current geosynthetic technology have significantly enhanced their application and effectiveness across various engineering fields. Developments in geosynthetic technology that can be translated to mine rehabilitation efforts include:

7.1 Smart Geosynthetics

Integration of sensors and monitoring devices into geosynthetics allows for real-time monitoring of structural health, strain, temperature, and environmental variables. This technology aids in the quick identification of potential issues, enhancing the performance evaluation and maintenance of geosynthetic systems.

7.2 Biodegradable and Sustainable Materials

There's a growing focus on producing sustainable geosynthetics with minimal environmental impact. Innovations include biodegradable geotextiles which decompose over time, reducing the long-term environmental footprint. This aligns with increasing demands for sustainable construction practices.

7.3 Enhanced Durability and Performance

New manufacturing techniques and formulations are improving the strength, durability, and environmental resistance of geosynthetics. These advancements include better resins, UV stabilisers, antioxidants, and other additives to extend the service life of geosynthetics that can be formulated to site specific applications.

7.4 Advanced Composite Materials

Geocomposites, combining multiple geosynthetic functions, have been refined to offer superior performance in areas like drainage, filtration, and reinforcement. For instance, geosynthetic clay liners (GCLs) with enhanced reinforcement provide better shear strength for use in steeper slopes or under more dynamic loads, or the blending of bentonite with other additives to serve additional functions such as contaminant adsorption.

7.5 Improved Interface and Internal Shear Strengths

Research has led to better understanding and manipulation of shear strengths at interfaces between geosynthetics and soil or between different geosynthetic layers (e.g. specific texturing types on geomembranes), reducing the risk of failure in applications like cell and capping liners or reinforced slopes.

7.6 Leak Detection and Geomembrane Technology

Advances in geomembrane and geotextile technology include better leak location systems and friction-enhanced designs, improving containment systems' reliability in applications like waste TSFs and process water storage.

7.7 Geosynthetic Applications in Transportation

Geosynthetics are seeing expanded use in road construction with innovations like geogrids designed for pavement reinforcement, or reinforcing geotextiles with in built wicking capability, leading to longer-lasting roads with reduced maintenance costs. This includes new geosynthetic products tailored for specific transportation challenges (such as haul roads), enhancing stability and performance.

7.8 Advances in Geosynthetic Testing

Geosynthetic laboratory testing is advancing in several key ways to ensure durability in mining environments:

Chemical compatibility testing - Laboratories are now conducting more comprehensive tests to evaluate the chemical resistance of geosynthetics against the harsh chemicals encountered in mining operations, such as acids and heavy metals. This includes accelerated aging tests where geosynthetics are exposed to simulated mining solutions to predict long-term behaviour under realistic chemical exposure conditions.

Enhanced durability tests - Testing for durability includes exposure to extreme temperatures, UV radiation, and mechanical stress. New standards and methods are being developed to simulate the unique conditions of mining sites more accurately, including cyclic loading to assess how geosynthetics perform under the heavy and repeated loads from mining equipment.

Interface shear testing - Given the importance of composite systems in mining applications, there's an increased focus on interface shear testing to understand how different geosynthetic materials interact with each other and with soil or waste materials. This helps in designing systems that can withstand the dynamic forces in a mining context.

Long-term performance simulation - Advanced tests simulate long-term performance by subjecting geosynthetics to conditions that mimic the lifetime of a mining operation or beyond, into the post-closure phase. This includes tests for hydraulic conductivity, tensile strength over time, and resistance to puncture and tear, which are crucial for applications like tailings dams and heap leach pads.

Geosynthetic clay liner (GCL) testing - GCLs are particularly critical in mining for their hydraulic barrier properties. Testing has evolved to include more sophisticated methods for evaluating hydraulic conductivity over time, especially in the presence of high ionic strength solutions typical in mining waste. This involves testing under various stress conditions and with different types of permeants.

Non-standard and custom testing - Customised tests (geotextile cushion performance, gradient ratio, etc) are being developed to address specific mining scenarios, such as the interaction of geosynthetics with specific ores, tailings, or process solutions. These tests help in tailoring geosynthetic materials to the exact needs of a mining application, ensuring better performance and longevity.

Accelerated weathering tests - These tests use controlled environments to speed up the aging process of geosynthetics, providing insights into how materials will degrade over time due to environmental factors like UV exposure, temperature fluctuations, and moisture. This is crucial for predicting the service life in outdoor mining conditions.

Integration of technology for real-time monitoring - While not strictly laboratory testing, advancements in sensor technology allow for real-time monitoring of geosynthetic performance in field conditions, which can then inform lab testing protocols to better mimic real-world scenarios.

These advancements ensure that geosynthetics used in mining can provide reliable performance over extended periods, even under the aggressive conditions found at mining sites. This comprehensive approach to testing helps in reducing environmental risks, enhancing safety, and improving the economic viability of mining operations by ensuring that geosynthetic solutions are robust and fit for purpose.

8.0 CONCLUSION AND RECOMMENDATIONS

The integration of geosynthetic materials in mine rehabilitation represents a transformative approach to addressing the environmental, economic, and technical challenges associated with mining operations. These advanced materials have demonstrated their versatility and effectiveness across various applications, including erosion control, water management, waste containment, and revegetation support. Case studies from successful projects highlight the tangible benefits of geosynthetics in reducing environmental footprints, enhancing long-term stability, and facilitating sustainable land reclamation.

Despite their clear advantages, challenges such as material degradation, design complexities, and regulatory compliance need to be carefully managed to maximise the potential of these materials. As the mining industry increasingly adopts sustainable practices, the role of geosynthetics will only grow in importance, supported by ongoing technological advancements and innovative applications.

Recommendations based on this white paper include:

Adopting best practices in design and implementation - Ensure thorough site assessments to identify the most suitable geosynthetic solutions. Use proper engineering designs that account for local environmental conditions, such as soil type, climate, and hydrology. Engage qualified professionals for design, supply, installation and quality assurance to avoid performance issues.

Investing in research and development - Support the development of more durable, environmentally friendly, and cost-effective geosynthetic materials. Encourage studies that address the long-term behaviour and degradation of geosynthetics under mine site conditions.

Enhancing stakeholder collaboration - Foster partnerships between mining companies, geosynthetic manufacturers, regulatory agencies, and local communities. Promote knowledge-sharing initiatives to disseminate lessons learned from successful mine rehabilitation projects.

Integrating digital technologies - Use digital tools, such as remote sensing and monitoring systems, to track the performance of geosynthetics in real time. Leverage data-driven insights to optimise maintenance and ensure compliance with environmental standards.

Aligning with regulatory frameworks - Stay updated on evolving environmental regulations and guidelines for mine rehabilitation. Work proactively with regulators to demonstrate the environmental benefits of geosynthetics and achieve compliance.

Promoting awareness and training - Conduct training programs for engineers, site managers, and contractors on the use and benefits of geosynthetics. Raise awareness among stakeholders about the potential of geosynthetics to enhance mine rehabilitation outcomes.

By following these recommendations, the mining industry can harness the full potential of geosynthetic materials to achieve more sustainable and effective rehabilitation outcomes, contributing to environmental restoration and long-term community benefits.

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