Analyzing the consequences of improper storage and preservation techniques on geomembrane integrity

Y.D. Ntow, J. Sampah- Adjei, D. Johnson, J. Cobbinah, E.M. Melomey
Constromart Investments Ltd, Accra, Ghana

ABSTRACT: Geomembranes play a crucial role in numerous industries by providing containment and protection for various materials and scenarios. In Ghana, these geomembranes are particularly important in engineering applications such as water containment systems, environmental protection measures, mining activities, landfill liners, and covers. Their purpose is to prevent the migration of toxins into the surrounding soil and groundwater, thereby reducing the risk of pollution and harm to the environment. However, improper handling, storage, or preservation of geomembrane materials can have severe consequences on their performance, posing risks to both the environment and the economy. This paper focuses on the specific implications of inadequate storage and evaluates preservation techniques that aim to maintain the quality and integrity of geomembranes used in landfill liner systems. The study examines the physical and chemical properties of geomembranes when exposed to UV light and other environmental elements. Laboratory testing is conducted on both an adequately preserved and an unpreserved geomembrane, with the results compared to the GRI - GM13 Standard Specification for HDPE geomembranes. The findings highlight the importance of suitable storage and preservation strategies in ensuring the long-term durability and performance of geomembranes against environmental degradation in landfill applications.

KEYWORDS

Environment, Geomembranes, Integrity assessment, Landfill, Preservation techniques

1 INTRODUCTION

Geomembranes have emerged as indispensable components, effectively bridging the gap between environmental protection and industrial development. Geomembrane, as defined by ASTM D4439-00, is a synthetic material that effectively resists chemicals, UV radiation, and mechanical stress. It is composed of one or more synthetic sheets. Commonly used materials for geomembranes include Polyvinyl chloride (PVC), chlorosulfonated polyethylene (CSPE), linear low-density polyethylene (LLDPE), and high-density polyethylene (HDPE). These geomembranes play a crucial role in various engineering and environmental applications.
Geomembranes are utilized extensively in sectors such as water treatment, civil engineering, mining, agriculture, and waste treatment industries. In the context of Ghana, the significance of employing geomembranes in engineering practices to protect the environment, particularly in applications, in engineered landfills cannot be overstated (Dwipayana et al., 2019).

These adaptable synthetic materials provide crucial ways to reduce pollution, preserve water supplies, stabilize soil, and safeguard the environment from different human activities. However, it is crucial to recognize that the consequences of inadequate preservation and storage of geomembranes can lead to notable repercussions. When these valuable materials are not managed properly, they are susceptible to a variety of adverse effects. These encompass phenomena such as UV degradation, thermal degradation, swelling, oxidative degradation, and biological degradation, all of which can compromise the integrity and functionality of geomembranes. The repercussions of inadequate storage can extend even further, including significant human safety risks. A breach in the specification of the geomembrane liner due to improper storage can result in the uncontrolled contamination of hazardous substances. This event can compromise human well-being and safety by potential contamination of drinking water sources, thereby exposing community members to toxic chemicals that can cause severe health issues such as acute poisoning, developmental disorders, and long-term illnesses such as cancer. Additionally, releasing hazardous substances into the environment can lead to immediate dangers, including land degradation and air pollution which pose risks of injury or death to workers, nearby residents and animals. Furthermore, direct exposure to toxic fumes or contact with hazardous materials can result in acute medical conditions such as respiratory distress, chemical burns, and other severe health problems Additionally, when pollutants escape confinement due to incorrect storage of geomembrane practices, they can infiltrate and contaminate soil, water bodies, and ecosystems. This does not only undermine the geomembrane's efficacy as a protective barrier but also exacerbates environmental contamination.

The primary objective of this study is to investigate and assess the crucial consequences of improper storage and preservation techniques on the integrity of geomembranes specifically high-density polyethylene geomembranes, with a particular emphasis on their use in landfill liner systems. The high-density polyethylene geomembranes contain 96-97.5% polyethylene, 2-3% UV protection, often carbon black, and 0.5-1.0% antioxidants as well as possess superior mechanical properties, great chemical resistance and favourable welding conditions hence being commonly utilized as liners in environmental construction projects (Giroud, 1984; Lavoie et al., 2020). Additionally, significant insights and practical recommendations for prolonged efficiency and resilience of geomembrane barriers in landfill engineering methods will be provided in this paper.

2 MATERIALS AND METHODS

2.1 Materials

The research was conducted on 2mm thick HDPE geomembrane rolls that had been stored at a site located in Accra, Ghana with geographical coordinates of 5° 40' 0" North, 0° 22' 0" West. The research focused on the impact of improper storage and preservation practices on the integrity of high-density polyethylene (HDPE) geomembranes.
The selected HDPE geomembrane rolls with smooth surfaces were divided into two experimental groups for the research: one labelled as "high exposure" and referred to as Sample A, and the other categorized as "medium exposure" and designated as Sample B. The group labelled "high exposure" experienced direct exposure to the prevailing environmental conditions at the study site, while the medium-exposed group was subjected to less or no direct exposure to the prevailing environmental conditions as shown in Figure 1. Over ten years, the geomembrane rolls were subjected to a range of environmental stressors, including temperature variations, UV light exposure, moisture exposure, and other pertinent factors such as microbial growth and abrasion or physical damage.

Figure 1. Rolls of HDPE Geomembranes in the study area

Table 1: Initial values of Smooth 2mm HDPE geomembrane's properties.

Property	Standard	Unit	Standard Value
Thickness	ASTM D5199	mm	≥ 2.00
Density	ASTM D792	g cm^{-3}	≥ 0.940
Carbon black content	ASTM D4218	%	2-3
Tensile stress	ASTM D6693	MPa	29
Yield elongation	ASTM D6693	%	12
Tear resistance	ASTM D1004	MPa	249

2.1 *Methods*

The study employed a two-phase approach, commencing with an extensive review of existing literature, followed by laboratory assessments of the targeted geomembranes. A series of laboratory tests were conducted following well-defined protocols to thoroughly investigate the impacts of improper storage and preservation methods on the integrity of the geomembranes. These experimental procedures were formulated to assess crucial physical and mechanical attributes of the geomembrane specimens, providing valuable insights into the potential deterioration resulting from inadequate storage circumstances.

2.1.1 *Tensile properties test*

In line with ASTM D4595 standards, the tensile strength characterizes a material's maximum resistance to deformation under external tensile forces. Concurrently, tensile stress denotes the force per unit area acting outwardly on a material (Rowe & Sangam, 2002). The assessment of the HDPE geomembrane's tensile properties, including tensile strength and stress at a specific elongation (13%), adhered to the ASTM D6693 guidelines. For this study, twenty (20) test specimens were meticulously prepared - ten (10) for each sample denoted by Sample A and B. Employing a die, the specimens were shaped into dumbbell forms. Each sample resulted in five (5) specimens, divided evenly between longitudinal and transverse orientations. Rigorous scrutiny was applied to ascertain all specimen surfaces. The mechanical evaluation using the Tinius Olsen Universal Testing Machine, aligned with the principles of ASTM D6693. This testing apparatus, interfaced with the Horizon software as depicted in Figure 2(A, B), facilitated the assessment of HDPE geomembrane samples.

2.1.2 *Carbon black content*

In accordance with ASTM D4218 standards, the Carbon Black Content test was executed. This method allows for the quantification of carbon black levels within the HDPE geomembrane samples. This evaluation is pivotal as it holds a crucial role in safeguarding the geomembrane against ultraviolet radiation. Approximately 1.0 gram of the conditioned sample was placed in a metallic crucible, which was then weighed. The specimen underwent pyrolysis within a muffle furnace for a brief duration. During this process, the furnace environment became oxygen-deficient to prevent the combustion of residual carbon black. After cooling in a desiccator and weighing to determine residual carbon black, the crucible and its contents were returned to the furnace. This step helped ascertain ash content, enabling the calculation of the authentic carbon black content.

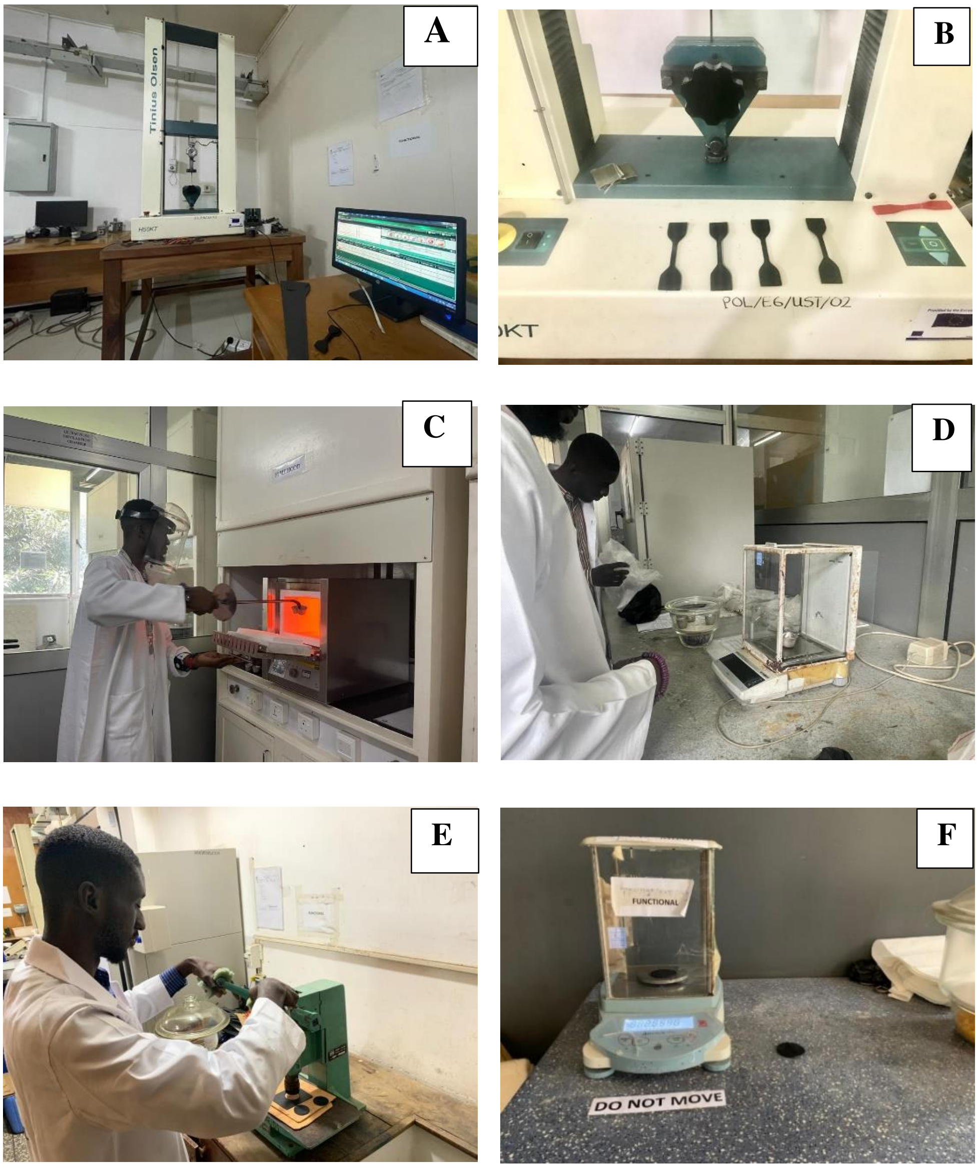
2.1.3 *Density of HDPE Geomembrane*

The density assessment of the HDPE geomembrane samples involved several steps.
Initially, round test specimens were prepared using a circular die with a 44mm diameter. The thickness of each specimen was measured with a vernier caliper. By utilizing the measured diameter and thickness, the volumes of these specimens were computed. The density of the HDPE

geomembrane samples was subsequently determined by dividing their masses by their respective volumes.

2.1.4 *Tear resistance*

The tear resistance evaluation was performed in accordance with ASTM D1004 standards. For this objective, specially shaped specimens were created from HDPE geomembrane samples. The Tinius Olsen Universal Testing Machine, shown in figure 2 (G, H) below, was used to test the tear resistance of five specimens of Sample A and Sample B. The specimen's structural design within this testing technique is important since it results in the development of concentrated stress inside a small portion of the specimen. The tear resistance value, reported in Newtons, represents the maximal stress point at which tearing begins. Stress, in this context, refers to the force applied per unit area of the geomembrane. This value is typically observed near the point where tearing initiates, indicating the geomembrane's ability to withstand tearing forces before failure.



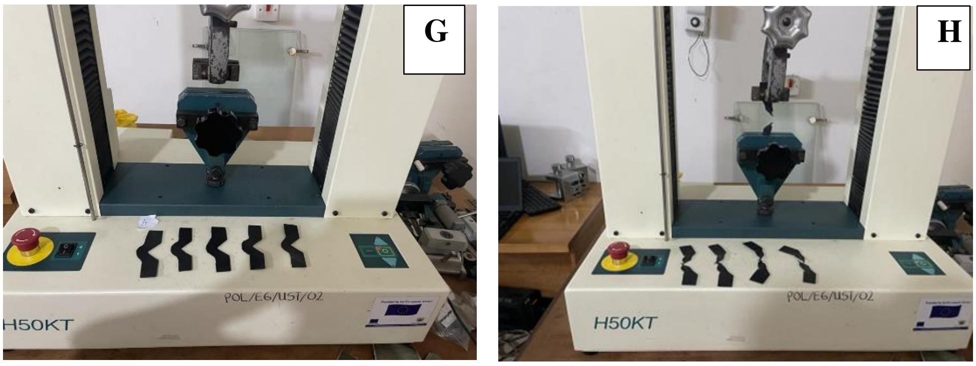


Figure 2. (A,B) Tensile properties test setup, (C,D) Carbon black content, (E,F) Density , (G,H) Tear resistance

3 RESULTS AND DISCUSSION

3.1 *Tensile properties test results.*

Table 2 presents a comprehensive analysis of the changes in critical tensile properties, including parameters such as tensile strength, stress at 13% strain level, and percent yield elongation for both the longitudinal and transverse directions, allowing for a thorough understanding of material behaviour. Regarding Sample A, which experienced a significant degree of exposure to atmospheric conditions such as temperature variations, UV light exposure, its tensile strength underwent a reduction of 10% in the longitudinal direction and 9.3% in the transverse direction. In contrast, Sample B displayed notably more resilient characteristics. In the longitudinal orientation, there was a minimal decline of 1.0% in tensile strength, while in the transverse orientation, a modest decrease of 4.5% was observed. This minimal decline in tensile strength in the longitudinal orientation and the modest decrease in the transverse orientation can be explained by the manufacturing-induced anisotropy, differences in stress distribution, and potential defects within the geomembrane material

At an elongation of 13%, both Sample A and Sample B exhibited consistent trends of diminishing tensile stress. However, Sample A demonstrated remarkable alterations. In both Sample A and Sample B, a nearly identical reduction in tensile stress of approximately 53% was observed in both the longitudinal and transverse orientations.

Samples A and B exhibited yield elongation percentages in both the longitudinal and transverse directions that deviated significantly from the minimally acceptable threshold of 12%. This considerable variance indicates a notable shift in the material's response to stress. In specific measurements, Sample A demonstrated a longitudinal yield elongation of 1430 and a transverse yield elongation of 1470, while Sample B displayed values of 1550 longitudinally and 1440 transversely. Importantly, these figures exceeded the established 12% standards, implying the material surpassed its elastic limits.

This occurrence holds substantial consequences. When a geomembrane surpasses its yield elongation threshold, it signifies a compromise in the material's ability to endure applied strain without undergoing permanent deformation or failure. Moreover, this alteration significantly impacts the overall structural soundness and functional efficacy of the geomembrane.

Table 2. Summary of laboratory test results

Property	Standard	Test Value		Specification
		Sample A	Sample B	
Thickness	ASTM D5199	2.00	2.00	≥ 2.00 mm
Tensile strength				
• Longitudinal	ASTM	26.1	28.7	≥ 2.9×10^4 kN/m²
• Transverse	D6693	26.3	27.7	
Tensile stress at 13% elongation				
• Longitudinal	ASTM	12.75	13.05	≥ 29.00 MPa
• Transverse	D6693	13.00	14.21	
Percent yield elongation				
• Longitudinal	ASTM	1470	1550	12 %
• Transverse	D6693	1430	1440	
Tear resistance				
• Maximum resistance	ASTM	8.54	9.17	≥2.49×10^5 kN/m²
• Maximum extension	D1004	173.31	186.22	
Carbon black content	ASTM D4218	0.896	1.245	2 - 3%
Density	ASTM D792	0.873	0.887	≥ 0.940

The findings emphasize the significance of effective HDPE geomembrane storage and exposure control. This observation has important implications, signalling that the geomembrane's ability has been compromised, affecting the overall structural integrity and functional effectiveness of the geomembrane. The inability to satisfy specification criteria might be linked to inadequate material preservation, which exposes the materials to unfavourable weather conditions and subsequent degradation (Lavoie et al., 2020).

3.2 *Carbon black content*

As shown in Table 2, Sample A had a carbon black concentration of 0.896, which was a significant 55% decrease from the standard specification. Sample B, on the other hand, showed a content of 1.245, a 38% decrease. Both geomembranes varied from the standard 2-3% range, indicating an error from the desired composition. However, when considering the geomembranes' exposure to the environment, an intriguing contrast arises. Sample B, which had medium exposure to atmospheric conditions, had a larger carbon black concentration than Sample A, which had higher exposure levels. This subtle observation emphasizes the critical importance of carbon black concentration in protecting geomembranes against UV-induced destruction (Giroud 1994). Furthermore, these studies highlight the consequences of inappropriate storage. The negative impacts on geomembranes underscore the importance of proper storage techniques. This includes shielding them from direct sunlight, controlling temperature fluctuations, and maintaining optimal humidity levels to preserve carbon black content and overall material performance. The geomembranes are inappropriate for their intended uses due to the decreased carbon black concentration, which directly affects UV resistance.

3.3 *Tear resistance*

The tear resistance test was conducted on Sample A and Sample B to assess their strength and deformation characteristics. Key test factors, maximum resistance and maximum extension are crucial indicators of a material's tearing performance. Maximum resistance signifies the highest force a material can endure before tearing, demonstrating its inherent strength against abrupt, high-stress tearing. Conversely, maximum extension refers to a material's maximum deformation capacity before collapsing, relevant for energy absorption and stress distribution during gradual tearing. Comparative analysis of results in Table 2 revealed that Sample B outperformed Sample A in both maximum resistance and maximum extension. This suggests Sample B's superior resistance to tearing and greater deformability before failure compared to Sample A. Despite these advancements, both samples fell short of meeting industry tear resistance standards. The relationship between maximum resistance and maximum extension underscores the inherent trade-off between strength and flexibility. A material with high maximum resistance might be brittle, vulnerable to unexpected failure, while one with high maximum extension could absorb energy better but lack adequate strength against tearing stress.

3.4 *Density*

Sample A had a density of 0.873, which was 7% lower than the stipulated requirement. Sample B had a density of 0.887, representing a 5.6% decrease as shown in Table 2 above. In both cases, these values went below the stated criteria of 0.940, indicating material deterioration as a result of the prolonged exposure. When evaluating the relative amounts of exposure of the geomembranes, the consequences of extended exposure to UV light and environmental conditions become even more obvious. Sample A, which was greatly exposed, had a lower density than Sample B, which was exposed moderately. This association supports the idea that extended environmental stress can lead to chain scission, cross-linking and oxidation of polymer chains changing polymer structure and reducing molecular weight (Lavoie et al., 2020; Touze & Lambert, 2016). The geomembrane’s density thus decreases due to the breakage of polymer chains and changes in the packing arrangement. As a result, the ability of geomembranes to tolerate stress and the difficulties provided by environmental conditions may be impaired. The observed density decreases underscore the importance of considering the impact of proper storage techniques.

3.5 *Melt Flow Index*

The Melt Flow Index (MFI) is defined by ASTM D1238 guidelines as the weight of polymer (g) extruded within 10 minutes via a given capillary under controlled temperature and pressure conditions, utilizing a dead weight for pressure application. MFI is critical in assessing the flow properties of HDPE Geomembranes (Rowe et al. 2002; Shenoy & Saini 2016). This index measures how easily a thermoplastic material, such as HDPE, can be melted and extruded through a specified size. It is a critical indicator that evaluates the processability and flow behaviour of polymers during production, influencing processes, and estimating actual performance. MFI, which is often expressed in grams per 10 minutes (g/10 min), offers information on the molecular weight distribution, viscosity, and overall flow characteristics of materials. Temperatures ranging from 125 to 300°C and a range of applied dead loads ranging from 0.325 to 21.6 kg result in pressures ranging from 0.46 to 30.4 kg/cm2. The connection between the Melt Flow Index and the density of HDPE geomembranes is closely related to the structure and processing conditions of the polymer. Owing to the closer structure of elongated polymer chains, increased molecular weight often correlates with higher density. As a result of increased chain entanglement and interactions, higher density corresponds to a lower Melt Flow Index (higher viscosity). A lower MFI is often preferred in the context of HDPE geomembranes. A lower MFI indicates that HDPE has a higher molecular weight and viscosity, which provides advantages in terms of durability and long-term performance.

During the test analysis (Table 2), it became apparent that Sample B had a higher density than Sample A, even though both fell short of the specifications provided. This finding emphasizes Sample B's preferability which was medium exposed to environmental conditions, as measured by the Melt Flow Index testing parameter. This analysis emphasizes the important role of suitable HDPE geomembrane preservation strategies in determining its durability and longevity.

4 CONCLUSION

In conclusion, this paper has brought to light the critical role that robust storage and preservation strategies play in maintaining the integrity of geomembranes. It has illustrated how the proper storage practices directly impact the physical and chemical attributes of these materials. Considering the detrimental effects of UV light exposure and other elements such as microbial growth, abrasion or physical damage and mechanical stress, it is imperative to implement measures such as sheltered storage locations, UV-resistant covers, controlled humidity levels, and regular inspections.

By following these recommendations, stakeholders can ensure that geomembranes deliver optimal performance throughout their lifespan. Shielding geomembranes from adverse weather conditions not only prevents environmental contamination but also helps to avoid substantial economic losses, ultimately bolstering the overall success of engineering ventures.

The paper highlights the importance of suitable storage and preservation strategies in ensuring the long-term durability and performance of geomembranes against environmental degradation in landfill applications. Consistent adoption of good preservation methods will significantly contribute to prolonging the lifespan of geomembranes, enhancing their efficacy, and fortifying sustainability.

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