Short-term durability of elastomeric bituminous geomembranes at 70°C: A comparison of the effect of immersion methods

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Abstract. A custom-designed apparatus is used to age a 4.8-mm thick bituminous geomembrane (BGM) under single-sided exposure to a synthetic mining solution (pH13.5) at 70°C over a 6-months period. These experiments involve exposing the BGM from the bitumen coat surface only to simulate the BGM's chemical exposure conditions in the field. The degradation in the tensile and chemical properties of the BGM is compared to double-sided immersed coupons in which the BGM is exposed to the solution from both surfaces. The preliminary results show that the degradation rate of the mechanical properties of the BGM is higher in the double-sided immersion test than single-sided immersion test. However, the difference in the degradation rates of the chemical properties of the bitumen coat between the double-sided and single-sided immersed BGM samples was insignificant.

1 Introduction

Heap leaching is a process of extracting valuable minerals such as gold, silver, copper, uranium, and nickel from mined rocks using various chemical solutions [1]. Due to the combination of high vertical stress, extreme pH of the solution and high temperatures (sometimes more than 75°C), heap leaching is considered one of the most aggressive service environments for the geomembrane (GMB) liner [2,3,4,5]. Previous research has extensively examined the durability of polymeric geomembrane liners in heap leach pad applications under different field exposure conditions [5-9]. For example, Abdelaal and Rowe[8] investigated the degradation in physical and mechanical properties of a 1.5 mm thick high-density polyethylene (HDPE) GMB immersed in seven different mining solutions (pH 0.5, 1.25, 2.0, 9.5, 11.5, and 13.5) at temperatures between 95 and 40 °C for 3 years. The results showed that in all high pH solutions, degradation was observed in some physical and mechanical properties of GMB at 95 and 85°C [8].

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Bituminous geomembranes (BGMs) have relatively high puncture resistance and higher density than polymeric GMBs which make them suitable for geosynthetic barrier systems in mining applications [3,15,16]. BGMs consist of a nonwoven polyester geotextile (NW-GTX) and a glass fleece fibre fully impregnated and coated with Styrene-Butadiene-Styrene (SBS) modified bitumen.

Abdelaal and Samea [18] investigated the degradation behaviour of an elastomeric BGM by incubating the sealed BGM coupons in three different synthetic mining solutions with different pH and exposing them to temperatures ranging from 22 to 70°C over 26 months. The results showed that the BGM experienced faster degradation in its mechanical properties than its rheological and chemical properties in all mining solutions. Most studies focused on the chemical durability of BGM using the jar immersion test method (referred to double-sided immersion test) which has been used to age polymeric GMB by placing coupons in a jar filled with a synthetic solution at different elevated temperatures. This technique involves exposing the coupons from both surfaces and edges to the immersion solution, however, in the field exposure condition, the GMB is only exposed to the solution from the top surface and a nearly saturated soil from the bottom surface [19,20,21]. Simulation of the field exposure conditions was investigated by Abdelaal and Samea [22] by assembling a custom-designed apparatus (referred to as the Ageing Column) to age BGM in a single-sided exposure condition in synthetic municipal solid waste (MSW) leachate and a pH 11.5 mining solution at 55, 70, and 85°C. The mechanical, rheological, and chemical properties of the BGM were examined to compare the degradation in the BGM components to the double-sided immersion. The results showed that the ageing method does not have a significant effect on the rheological and chemical properties of BGM however, the single-sided exposure method reduces the degradation rates in their mechanical properties.

There is a paucity of research on using this custom-designed apparatus (Ageing Columns) for ageing BGM to compare the effect of exposure conditions on the degradation of BGM when exposed to various solutions and temperatures. New research is needed to provide a comprehensive understanding of the chemical durability of BGM under these service conditions to ensure that BGM can provide adequate environmental protection in different geoenvironmental applications with extreme pHs. The main goal of this study is to compare the degradation behaviour of BGM using double-sided and single-sided immersion techniques exposed to high pH 13.5 at 70ºC over 6 months.

2 Materials and methods

2.1 Bituminous geomembrane and immersion solution

The examined BGM (Table 1) has a nominal thickness of 4.8 mm with a mass per unit area of 5200 g/m^2. The reinforcement layers involve a polyester NW-GTX with a mass per unit area of 275 g/m^2 and a glass fleece sheet with a mass per unit area of 50 g/m^2 impregnated and coated with SBS-modified bitumen. The geotextile provides high mechanical properties while the bitumen provides waterproofing characteristics of the BGM. The glass fleece fibre is used to provide dimensional stability of the product during manufacturing and increase the strength and puncture resistance [10-11]. Stabilization with SBS reduces the bitumen's temperature sensitivity to make it suitable for various applications [12-13]. The top bitumen coat of the BGM was coated with sand to increase the interface shear strength of BGMs for better stability on side slopes [14] while the bottom surface was bonded to an anti-root polyester film [15]. The BGM was immersed in a synthetic pH13.5 to stimulate leachate found in the extraction of gold and silver [4]. Chemical constituents of the pH13.5 solution can be found in Table 2.

Table 1. Initial properties of the examined BGMs [23]

Property	Method	BGM
Commercial name		BGM 531-4m
Nominal Thickness (mm)	ASTM D5199	4.8± 0.120
Glass Mat. Reinforcement (g/m^2)	--	50
Mass Per Unit Area of the Nonwoven Geotextile Reinforcement (g/m^2)	ASTM D5261	275
Mass Per Unit Area of the BGM (g/m^2)	ASTM D5261	5200
Machine Direction Maximum Tensile Strength σ_M (kN/m)	ASTM D7275	33.1 ± 0.422
Machine Direction Elongation at σ_M (mm)	ASTM D7275	51 ± 1.8
Cross Machine Maximum Tensile Strength σ_M (kN/m)	ASTM D7275	29.5 ± 0.887
Cross Machine Elongation at σ_M (mm)	ASTM D7275	52 ± 1.5

Table 2. Chemical constituents of high pH 13.5 solution (in mg/L except for pH) [18]

Analyte	pH13.5
pH	13.5
Arsenic	0.45
Copper	10.3
Silver	0.3
Aluminum	0.3
Barium	0.1
Iron	0.006
Magnesium	3
Molybdenum	0.6
Nickel	0.08
Zinc	0.02
Potassium	100
Sulphate	20
Oxides	13

2.2 Immersion techniques

Two immersion techniques were used in this study to monitor the degradation of BGM in different exposure conditions. The first method is the jar immersion method or double-sided immersion test [24-25] which is typically use to investigate the degradation of GMBs. In this method, the BGM coupons were sealed by covering the edges using BGM strips and high-temperature silicone sealant (Fig.1-a), added in a jar filled with a specified solution and placed in oven at different temperatures. To simulate the field chemical exposure conditions and to examine the efficiency of sealing the edges in protecting the core geotextile from direct exposure to the solution, the custom designed Ageing Column (Fig. 1-b) [22] was used to age BGMs in single sided exposure. In this method, 5 BGM samples were placed between square stainless steel and assembled using Stainless steel bolts and nuts. The solution was introduced through ports located in each section on top of the BGM to allow exposure of the BGM to solutions from the top bitumen coat side only. A temperature controller was used to expose the BGM to the desired temperature. Both tests were running at 70°C and samples were extracted periodically to allow a comparison of the test results obtained from both immersion methods.

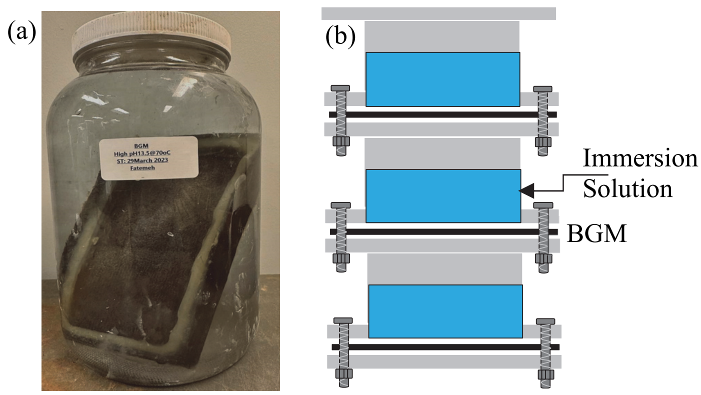

Fig. 1. Jar immersion test(a), Ageing Column(b)

3 Index testing methods

3.1 Tensile test

To monitor the mechanical properties of BGMs derived from NW-GTX, the tensile test (ASTM D7275) was conducted to evaluate the degradation in the reinforcement layer of the BGM. Tensile tests were conducted using Zwick Roell universal testing machine (Model Z020) with initial machine grips separation of 60 mm and at a constant strain rate of 50 mm/min. The tensile strength and elongation of the material were assessed by recording the maximum stress and the corresponding elongation which shows the starting point of failure in NW-GTX [26].

3.2 Fourier transform infrared spectroscopy

Fourier Transform Infrared spectroscopy (FTIR) technique was employed to monitor the chemical properties of BGM by identifying the changes in the functional groups of the elastomeric bitumen coat and SBS copolymer caused by ageing, using a Thermo Scientific Nicolet 203 iS20 instrument. The FTIR analysis was used within the wavenumber range of 4000-400 cm^{-1} and a resolution of 4 cm^{-1}. Samples were prepared by extracting a portion of the bitumen coat, fully dissolved in toluene (10% bitumen by mass) and applying the final solution on a potassium bromide disk to dry and examine it in an FTIR machine. The obtained results highlighted changes in the functional groups of both the bitumen and SBS copolymer attributed to variations in the carbonyl (C=O; centred around 1700 cm^{-1}) and butadiene double bonds (C=C; centred around 968 cm^{-1}) [27,28,29]. Thus, the degree of ageing of bitumen was characterized by using the carbonyl and butadiene indices [30-32] that can be calculated viz:

$$I_{C=O} = \frac{Area\ of\ the\ carbonyl\ band\ centered\ around\ 1700\ cm^{-1}}{\Sigma Area\ of\ the\ spetral\ bands\ between\ 4000\ and\ 600\ cm} \quad (1)$$

$$I_{SBS} = \frac{Area\ of\ the\ carbonyl\ band\ centered\ around\ 968\ cm^{-1}}{\Sigma Area\ of\ the\ spetral\ bands\ between\ 4000\ and\ 600\ cm} \quad (2)$$

where; $I_{C=O}$ = carbonyl index and I_{SBS} = butadiene index.

4 Results and Discussion

4.1 Comparison of the effect of immersion methods on degradation of BGM in terms of mechanical properties

The changes in maximum tensile strength and the elongation at the maximum tensile strength of the single sided and double sided immersed BGM samples in pH 13.5 at 70°C are presented in Fig. 2. The maximum tensile strength decreased to about 45% of the initial value in double-sided immersed BGM and 18% of the initial value in the single-sided immersed BGM over 6 months. For the elongation at maximum tensile strength, the values decreased to about 43% of the initial value in double-sided exposure and 31% of the initial value in single-sided exposure. The rate of reduction in maximum tensile strength and the elongation at maximum tensile stress were lower in single-sided compared to double-sided techniques. This is mainly due to the difference in the contact area of the BGM and the solution. In single-sided exposure, the BGM sample is in contact with the solution from bitumen surface. Thus, the interaction of BGM and the solution is less than in the double-sided exposure.

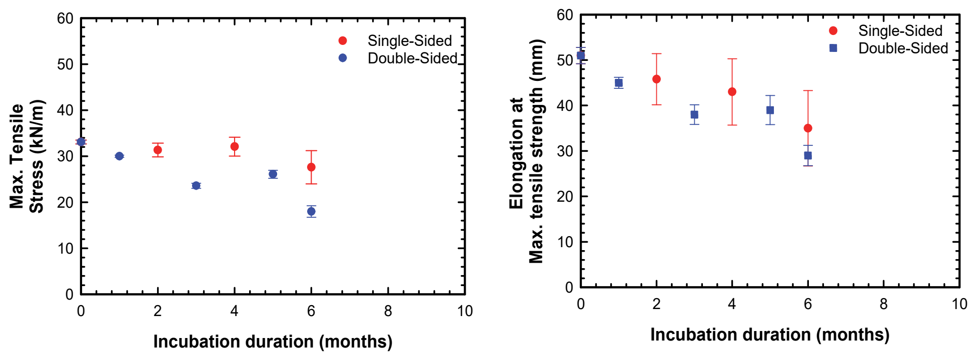

Fig. 2. Variation of tensile properties with incubation time at 70°C for double- sided and single-sided immersion method in high pH 13.5

4.2 Comparison of the effect of immersion methods on degradation of BGM in terms of chemical properties

The changes in chemical properties of BGM resulting from the exposure to pH13.5 in single-sided compared to double-sided exposure condition is presented in Fig.3 .The carbonyl index of unaged bitumen (0.0024) increased over 6 months to around 4 times the initial value for both methods. This increase in $I_{C=O}$ can be attributed to the cross-linking of the molecular structure of the bitumen as a result of the thermo-oxidative degradation [33]. In contrast, I_{SBS} slightly decreased in both immersion tests, reaching 90% of the initial value, implying a degradation in the SBS-copolymer stabilizing the bitumen coat. The results show that the degradation rate of the bitumen and SBS copolymer in the single-sided exposure was almost similar to the double-sided immersion. This is consistent with the Abdelaal and Samea's research which investigated the effect of single side versus double sided immersion but in different solutions [34]. Thus, the exposure conditions to the solution did not affect the rate of oxidative degradation of the bitumen coat.

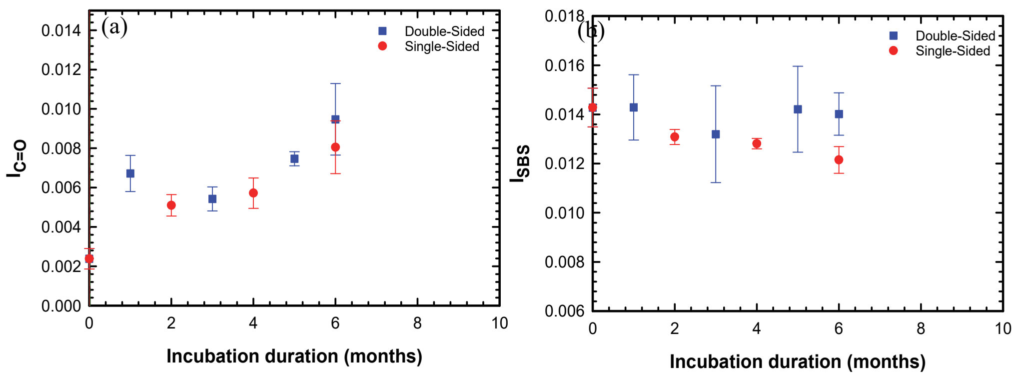

Fig. 3. Variation of carbonyl index (a) and Butadiene index (b) with incubation time at 70ºC for double-sided and single-sided immersion method in high pH 13.5

5 Conclusion

The effect of single-sided and the double-sided exposure to a high pH synthetic mining solution (pH 13.5) on the degradation behaviour of a 4.8 mm thick elastomeric BGM was investigated at 70ºC. A comparative analysis of the degradation behaviour of the chemical and mechanical properties of the BGM was presented for both techniques. The following conclusions were reached based on the conditions and the BGM examined:

- Exposing the BGM from the bitumen coat surface in single-sided exposure to high pH13.5 resulted in slower degradation rates in the mechanical properties relative to double-sided immersion in terms of maximum tensile strength and the elongation at maximum tensile stress at 70ºC over 6 months.
- The difference in the degradation rates of the chemical properties of the bitumen coat and SBS copolymer between the double-sided and single-sided immersed samples was insignificant. This suggests that the degree of oxidative degradation in the bitumen coat is only influenced by the solution in contact with the bitumen coat.

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