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Exhumation of HDPE geomembranes exposed to the weather for 10 years in a gold mining tailing

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Abstract. The durability study of a high-density polyethylene (HDPE) geomembrane that has been acting as a fluid barrier for 10 years in a gold mining dam/reservoir in Brazil was evaluated. The system stores waste considered hazardous, according to Brazilian legislation, with an average pH of 8 and presence of a cyanide solution. Samples exhumed after 10 years of service were exposed to the following three conditions: 1- only the weather; 2- contact with waste and exposure to the weather; 3- with field seams in contact with the tailings and exposure to the weather. Tensile strength, deformation under traction, tear resistance, puncture resistance and stress-cracking tests were carried out. With the use of statistical tools, the results obtained were compared with the GM13 standard. Through the results analysed, it was not possible to observe significant losses in the geomembrane's resistances or a significant increase in its tensile deformation. It was observed the geomembrane did not present significant alteration in 10 years of service, with stress crack exception. The geomembrane may be able to continue to perform the function for which it was designed. It is necessary to carry out additional tests and monitor the system to understand whether or not its low performance in stress crack test is affecting the flow barrier function.

1 Introduction

There are records that indicate geosynthetics have been applied in engineering works since the end of the 1950s [1, 2, 3]. For example, in 1959 geomembranes were installed in the Contrada Sabetta dam, in Italy [2].

Peggs [4] indicated ways to analyse the geomembranes durability through destructive tests on its seams. Gulec et al. [5] presented a durability study of geosynthetics exposed to acid mine drainage, in an environment with limited access to oxygen and radiation, during a period of 22 months. Touze-Foltz and Farcas [6] carried out an evaluation of bituminous geomembranes used as lining in lakes in France. Samples exposed in different periods were analysed, from 6 years of exposure to 30 years of exposure. None of the samples showed loss

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of flow reduction capacity that would interfere in the function for which they were designed. Abdelaal et al. [7] studied the durability of five different types of geomembranes in synthetic mining solutions with different pH of 0.5 and 13.5. The authors concluded that in alkaline environments the degradation of geomembranes occurred more intensely. It was emphasized that the behaviour and resistance of a geomembrane varies according to the solution type and environment in which this material is inserted [8].

This article addresses the study of the durability of a high-density polyethylene (HDPE) geomembrane that has been acting as a fluid barrier for 10 years in a gold mining dam/reservoir located in Brazil. The system stores waste considered hazardous [9], with an average pH of 8 and the presence of a sulphate and arsenic solution higher than permitted by Brazilian standard. Samples exhumed after 10 years of service were evaluated through its tensile strength, deformation under traction, tear resistance, puncture resistance and stress-cracking, in order to evaluate the durability of this material.

2 Case Study

This paper presents the results of an investigation carried out on a geomembrane lined pond in a gold mine in Brazil which contains waste from the beneficiation process, according to **Fig. 1**. The region where the dam is located has a warm and temperate climate, with much more rainfall in summer than in winter. The average temperature is around 19.6 °C and the average annual rainfall is 1258 mm.

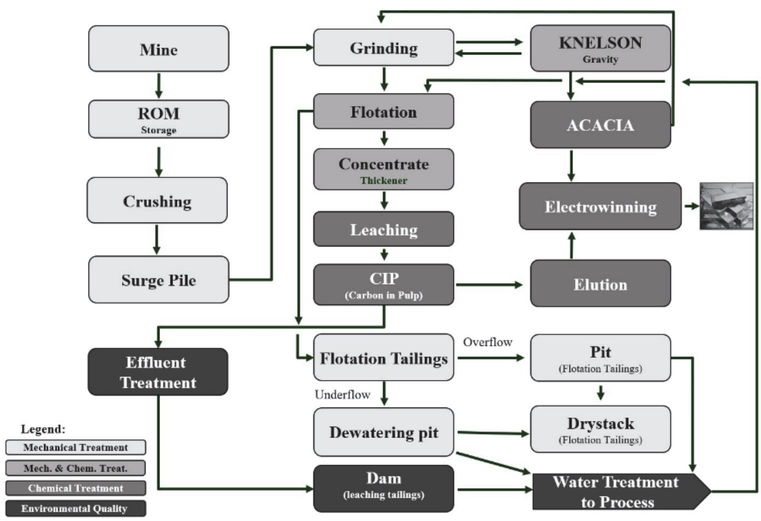


Fig. 1. Beneficiation process.

This process generates tailings with two different characteristics. Non-hazardous tailings from the flotation route are stored temporarily in two permeable open pits for dewatering, and then transported to a dry stack of tailings permanently. On the other hand, the leaching route uses cyanide to improve gold recovery. The cyanide tailings are stored in a liner dam, since it is hazardous. The HDPE 2,0 mm geomembrane analysed in this article was obtained in this liner dam. **Table 1** presents the tailings solubilization main parameters [10].

Table 1. Tailings solubilization main parameters.

Parameter	Tailings	Maximum value allowed	Unit
Arsenic	36,023	0,01	mg/L
Cyanide	0,005	0,07	mg/L
Iron	0,28	0,3	mg/L
Sulphate	370	250	mg/L
Solubilized pH	9,12	-	-

The geomembrane applied in this case study has the characteristics described in **Table 2**.

Table 2. Geomembrane characteristics.

Property	Test Specimens Number	Control Sample	Unit	Test standards (Reference)
Thickness	10	2.038 ± 0.040	mm	[11]
Density	5	$0.936 \pm 5.48 \times 10^{-4}$	g/cm³	[12]
Tensile Strength	10	55.946 ± 5.989	kN/m	[13]
Tensile Deformation	10	738.12 ± 62.83	%	[13]
Tear Resistance	10	327.49 ± 9.74	N	[14]
Puncture Resistance	5	869.76 ± 15.06	N	[15]
Stress-cracking	5	113.60 ± 11.76	Hours	[16]

In this article, three samples of the tailing's reservoir have been taken after 10 years of exposure. Each sample was subject to different boundary conditions, which are shown in **Table 3**. It is important to highlight that sample 1 was not in contact with the tailings during the exposure time, unlike samples 2 and 3, which were submerged and exposed to weathering alternately throughout this period.

Table 3. Samples.

Sample	Life time	Location	Conditions
1	10 years	Slope on the left bank (surface)	Weather and without tailings contact
2	10 years	Slope on the reservoir posterior edge, seam region (close to the surface)	Seam, weather and tailings contact
3	10 years	Slope on the reservoir posterior edge (close to the surface)	Weather and tailings contact

The exhumated samples were 1 m² surface area and were extracted considering the standard ISO 13437 [17]. Selection of sample locations depends on factors such as access conditions and operational costs. The reason for this is that exhumation must not generate any damage to the installed geomembrane in order not to cause leaking material. Exhumated samples are presented in **Fig. 2**. Each sample was evaluated through 10 specimens for tensile and tear strength test, the puncture strength and stress crack test were evaluated through 5 specimens.

(a) (b) (c)

Fig. 2. Exhumation process (a) sample 1; (b) sample 2; (c) sample 3.

3 Tests

The mechanical tests were performed in a universal machine. During the tests, tensile resistance and deformation were measured in a specified material's direction with a test speed of 50 ± 1 mm/min, according to ASTM D6693 [13]. Puncture and tear resistance tests were made in the same equipment with measurements of applied loads with test speed of 51 and 300 ± 1 mm/min, according to ASTM D1004 [14] and ASTM D4833 [15], respectively.

The stress crack resistance was determined with utilization of a specific equipment by applying a constant load of 30% of the yield tensile strength of the samples (precision of 10 g). The samples were immersed in a solution with 10% of Igepal and 90% or water at a temperature of 50°. For sample preparation a notch was made with 20% of the specimen's thickness (precision of 0,001 mm).

4 Results and Discussions

Through the durability tests results it was possible to apply statistical tools to evaluate the geomembrane durability compared with the GRI specified GM13 geomembrane [18] parameters. This comparison was not made considering the project's parameters, since it was not possible to access this information. **Table 4** and **Table 5** show the durability test results and the GM13 parameters values.

Table 4. Tensile strength and elongation average results compared to GM13 parameters values.

Sample	Tensile strength [kN/m]		Elongation [%]	
	Test result	GM13	Test result	GM13
1	56.7	53.0	738.6	700.0
2	52.8		757.4	
3	51.7		700.1	

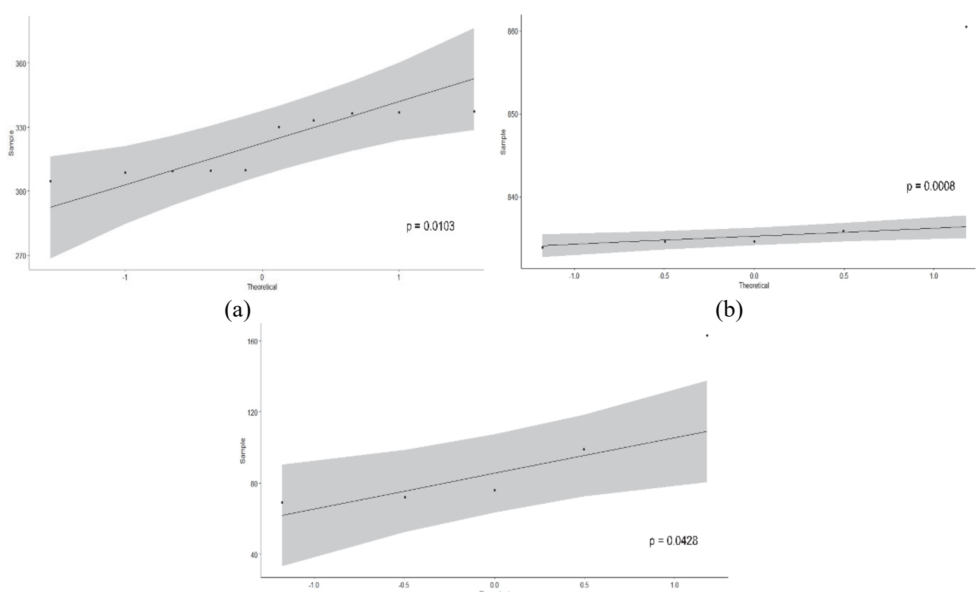
Table 5. Stress crack, tear and puncture strength average results compared to GM13.

Sample	Tear strength [N]		Puncture strength [N]		Stress Crack [h]	
	Test result	GM13	Test result	GM13	Test result	GM13
1	327.8	249.0	898.12	640.0	160.4	500.0
2	315.1		840.98		107.2	
3	321.6		839.90		95.8	

A normality test was performed to verify data adherence to a normal distribution, using the Shapiro-Wilk test through R software (version 4.1.2 2021-11-01). **Table 6** shows the Shapiro-Wilk p value obtained for each sample in each durability test. It was possible to notice that p value for the sample 3 in tear, puncture and stress crack tests were $p < 0.05$ (presented in bold), which means they were not normally distributed with 95% confidence, according to Shapiro-Wilk hypothesis. However, it's essential to highlight the limitations of the Shapiro-Wilk test, particularly that its statistical power diminishes significantly with very small sample sizes. Considering the presented limitation and aiming to confirm this evidence of non-normality, Q-Q(quantile-quantile) plots were drawn for the tear, puncture strength and stress crack test (**Fig. 3**).

Table 6. Shapiro-Wilk value.

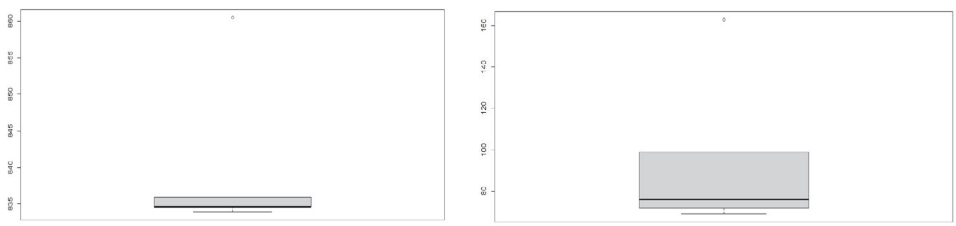
Sample	p value				
	Tensile strength	Elongation	Tear strength	Puncture strength	Stress Crack
1	0.7646	0.2175	0.0990	0.0616	0.8180
2	0.2360	0.4828	0.8625	0.7625	0.4030
3	0.3384	0.5081	**0.0103**	**0.0008**	**0.0428**



(a) (b) (c)

Fig. 3. Q-Q plots (a) tear strength; (b) puncture strength; (c) stress crack.

In **Fig. 3**, the variable empirical quantiles were compared with the normal distribution theoretical quantiles with mean 0 and variance 1 (hatched area). Although Sample 3 presented a p-value<0.05 for tear strength test, its Q-Q plot shows through its values that the sample might present normal distribution. For the puncture strength and stress crack test dots that might represent outliers could be observed, which probably indicate failures during test execution. To confirm whether those dots were outliers or not, boxplots graphics were drawn for these tests (**Fig. 4**).



(a) (b)

Fig. 4. Boxplot (a) puncture strength; (b) stress crack.

It was possible to observe outliers on **Fig. 4**, which might also have influenced those values of p<0.05. Therefore, all samples in all durability tests were considered to be normally distributed. In this context, confidence intervals (CIs) at the 95% level were calculated using the Student's t-distribution because the results followed a normal distribution, and the population average was unknown (**Fig. 5** to **Fig. 9**).

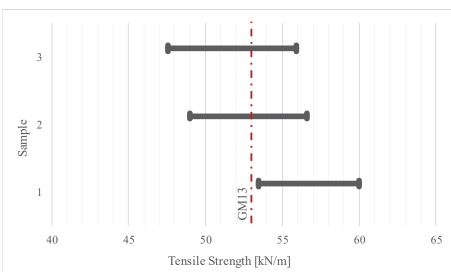


Fig. 5. Tensile strength confidence interval.

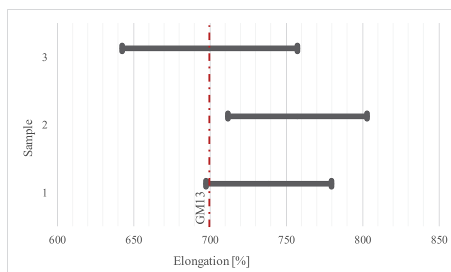


Fig. 6. Elongation confidence interval.

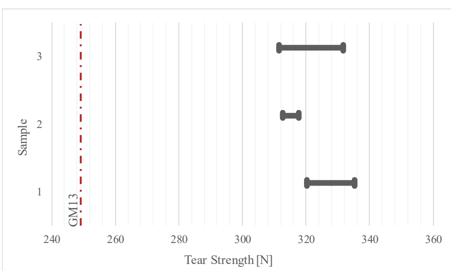


Fig. 7. Tear strength confidence interval.

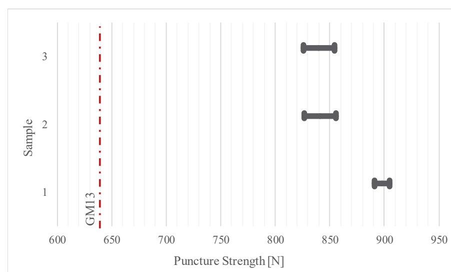


Fig. 8. Puncture strength confidence interval.

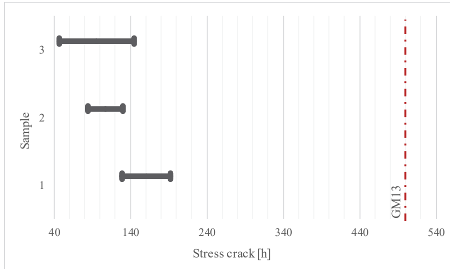


Fig. 9. Stress crack confidence interval.

Through the analysis of confidence intervals, it became evident that all the tested samples displayed a stress crack performance relative to the GM13 requirements that did not meet the specified criterion. However, until the writing of this article, no cracks were observed on the geomembrane. With the exception of the aforementioned case, all samples demonstrated sufficient durability performance when compared to GM13 standards. However, it's worth noting that, despite meeting the minimum values set by GM13, sample 3 (exposed to weather and tailings contact) consistently showed the lowest resistance values across all durability tests. This finding highlights the significant impact of chemical weathering (tailings exposure) on the durability of this geomembrane.

5 Conclusions

The durability of a high-density polyethylene (HDPE) geomembrane that has been acting as a fluid barrier for 10 years in a gold mining dam/reservoir located in Brazil was evaluated. Although the analysed variables presented adherence to the normal distribution, it might be possible a better adherence to other distributions. Thus, non-parametric statistics tools might obtain a probability density function that better represents its distribution, consequently improving the geosynthetic durability understanding. In addition, the number of specimen limitation is noted, which might impair the adherence distribution analysis. Therefore, in these cases, the use of resampling tools is recommended.

With the exception of stress crack performance, the geomembrane did not present significant alteration after 10 years of service. It is necessary to confirm the apparent good performance by carrying out additional tests. Furthermore, monitoring of the system is required to understand whether its low performance in stress crack is affecting the function for which it was designed (flow barrier).

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