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Geomembrane under Severe Environmental Conditions – A Mining Application

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ABSTRACT
Derived from landfill practice, the application of liners to control seepage from Tailings Storage Facilities (TSF) has increased over the years. Environmental acceptability of liner design will depend on post closure, long-term performance and contingency measures, and can be a key environmental issue in TSF permitting. The suitability of geosynthetics for long-term applications for waste containment in the mining industry is still being scrutinized. While short and medium term (up to ~ 30 years) geosynthetics performance data is available in various situations, long-term field performance data is non-existent and, to date, available predictions have been based primarily on laboratory tests and modeling. These factors may be contributing reasons for the limited use of geosynthetics to address long-term issues such as the control of Metal Leaching (ML) and acid rock drainage (ARD). In order to bring contribution to the understanding of field performance of liners applied to control seepage in a TSF for leach tailings containment, this paper presents results from mechanical assessments on an exhumed HDPE geomembrane submitted during a year to several environmental conditions, such as UV exposure, changes temperature, changes in pH and changes in mechanical stress, that in synergy can accelerate degradation.

RESUMO
O emprego de sistemas de revestimento de fundo para controle de percolação em áreas com risco de contaminação tem aumentado continuamente, mas sua aceitação ambiental depende do comportamento de longo-prazo, das condições pós-fechamento e das medidas de contingência adotadas, e pode ser a chave para a autorização de funcionamento do empreendimento. Embora dados de desempenho de geossintéticos de curto e médio prazo (até ~ 30 anos) estejam disponíveis em várias situações, dados de desempenho de campo de longo prazo são inexistentes e as previsões atuais se baseiam principalmente em ensaios e modelagem de laboratório. Buscando contribuir para a compreensão do comportamento destes sistemas de revestimento, este artigo apresenta resultados do comportamento mecânico de uma geomembrana de polietileno de alta densidade exumada após um ano de exposição sob condições ambientes severas, tais como radiação UV, variação de temperature, pH e solicitações mecânicas, processos que em sinergia podem acelerar a degradação.

1. INTRODUCTION

A wide range of geosynthetics is employed in the mining industry to improve the performance of mineral processing and meet the needs of environmental applications. One of the major uses of geosynthetics materials in mining is geomembrane liners to contain fluid migration, e.g. process solution pond liners, heap leach facilities liners, tailings impoundment liners (Lupo and Morrison 2007).

The nature and location of mining operations provide challenging conditions to geomembrane liner systems. Loading conditions, for instance, involve ore production rates and placement methods that expose the geomembrane to rapid changes of stress. More often than not, lined tailings impoundments and heap leach pads are designed with extreme ore heights, which results in significant normal stresses. Climate and elevation configure another key point, because the geomembrane may be exposed to extreme ranges of temperature, solar radiation and wind. Additionally, the process solutions that are used in these operations, because they may be very acidic or basic and may affect the properties of the geosynthetics in a long-term scenario.

Mining facilities, mainly the structures for tailings containment with high level of contamination, need to be lined with geosynthetics in order to prevent the uncontrolled release of contaminated material and, thus, preserve the environment during operation and closure. Water and leach tailings reservoirs, for instance, generally have exposed geomembranes in the upper parts and spillways. Geomembranes placed in the upper parts and spillways are especially subjected to several degradation conditions with synergetic effects.

The geomembrane evaluated in this paper was exhumed during the replacement of a liner in a leach tailings reservoir. This reservoir is situated in a central region of Brazil, that has a great energy and mineral potential. The present paper explores the environmental behavior of an HDPE geomembrane liner along a leach tailings pond system. This liner has been left exposed for 12 months and received the leached effluent during approx. 7 months. Sampling took place on a panel exhumed from the system and experimental investigations were made to evaluate the effects of weathering and chemical degradation over that period.

2. SAMPLING CONDITION

2.1 *Location*

The sample was exhumed from a leach tailing reservoir in October 2017, exactly one year after its installation. It was in an area most of the time exposed to high insolation and low level of rain. This was roughly 30m away from the crest. Approximately sixty percent of the sample central part received the effluent of the leach tailings from January to July 2017. The flow was continuous with a water depth of ~30cm.

2.2 *Geomembrane properties*

The geomembrane is a 1.5mm thick HDPE geomembrane whose batch quality certificate showed the properties indicated in Table 1. The resin density of the polymer is 0.938 g/cm³, classified as medium density (ASTM D792). The manufactured geomembrane density was increased to 0.949 g/cm³ by the addition of 2.5% (by mass) carbon black and other additives. The geomembrane met all the minimum requirements specified. The results of ASTM D6693 and D1004 should present the results in machine and cross machine direction, therefore, sometimes only the mean value is checked on receipt.

Table 1 - Geomembrane properties and minimum requirements.

Property	Method	Unit	Obtained Mean value	Specification Minimum requirement
Nominal thickness	ASTM D 5199	mm	1.53	>1.5
Geomembrane density	ASTM D 792	g/cm^3	0.949	>0.940
Strength at yield	ASTM D 6693	kN/m	28.1	>22
Elongation at yield	ASTM D 6693	%	16.1	>12
Strength at break	ASTM D 6693	kN/m	44.8	>40
Elongation at break	ASTM D 6693	%	824.8	>700
Tear resistance	ASTM D 1004	N	248.2	>187
Puncture resistance	ASTM D 4833	N	621.7	>480
Carbon black	ASTM D 4218	%	2.5	2 a 3
Carbon black dispersion	ASTM D 5596	Category	1	1 or 2

3. DEGRADATION FACTORS

3.1 *Mechanisms*

Bottom liner systems are expected to experience some degradation (or aging) over time, which will eventually culminate in their failure. Major mechanisms through which degradation can occur are (Rowe and Sangam 2002, Koerner et al. 2017, Hsuan et al. 2008): swelling, degradation by extraction, biological degradation, photodegradation (UV light) and oxidative degradation.

Swelling of an HDPE or other polymeric liners happens when they are exposed to liquids, either water or leachate, and manifests through the absorption of organic compounds from process solutions such as those used in copper, gold and uranium ore extraction (Hornsey et al. 2010). Such absorption generates large bulges on the geomembrane, consequently inducing stresses on localized areas, e.g. heat affected areas of welds. Degradation by extraction also arises wherever the geomembrane is in contact with liquids, and the rate of extraction (i.e. extractability) is controlled by the dissolution of one or more components from the surface and the diffusion from the interior structure to the surface (Hsuan and Koerner

1998). Extraction can be critical for HDPE geomembranes at typical temperatures in leachate containment systems (Smith et al. 1992).

Biological degradation occurs when the polymer is attacked by living organisms in the soil. These include a variety of agents, ranging from large-size animals such as capybaras, rats and wild dogs to fungi and bacteria. The greatest concern about fungi and bacteria is actually not polymeric degradation, but clogging of drainage systems often constructed adjacent to the liner (Koerner 2012).

Photodegradation, in other words, degradation induced by UV or visible light, is an important source of degradation to all organic materials, including polymers. Geomembranes are buried in liner applications, which eliminates UV degradation except during construction or exposure. The consequences of being exposed for a relatively long time include discoloration, surface cracks, brittleness and eventually decrease in mechanical properties (Beach and Kissin 1986). In order to hamper UV degradation, carbon black is added to the geomembrane formulation.

Oxidative degradation happens when the polymer reacts with oxygen and have its molecular structure and morphology altered (Rowe and Sangam 2002). Covered geomembranes are subjected to less oxidation, but, when the geomembrane is exposed, oxygen can be extremely aggressive to the polymer structure. As a result, mechanical and other properties might decrease beyond acceptable limits. Antioxidants additives are added to the compound to retard oxidation reactions and, thus, ensure long-term service life of the product.

In field applications, the geomembrane is likely to undergo synergistic effects that could increase the rate of polymer degradation. The liner, for instance, may have leachate with anaerobic conditions above it and a partially saturated leak detection system below, where oxygen exists. In addition, temperature variations derived from the decomposition of waste together with local stresses complicate the situation even more. So, it is crucial that these several phenomena are taken into account when assessing the lifetime of the geomembrane.

3.2 *Local conditions*

3.2.1 Climate conditions

Monthly values of global radiation, total insolation and total precipitation are illustrated in Figure 1, while Figure 2 presents the average maximum and average minimum temperatures and relative humidity. Global sola radiation was estimated considering the average monthly values proposed by Reis and Tiba (2016) for the region, giving for one year of expositure 1967 kWh/m^2 The other values were obtained from a local meteorological station of INMET (National Institute of Meteorology).

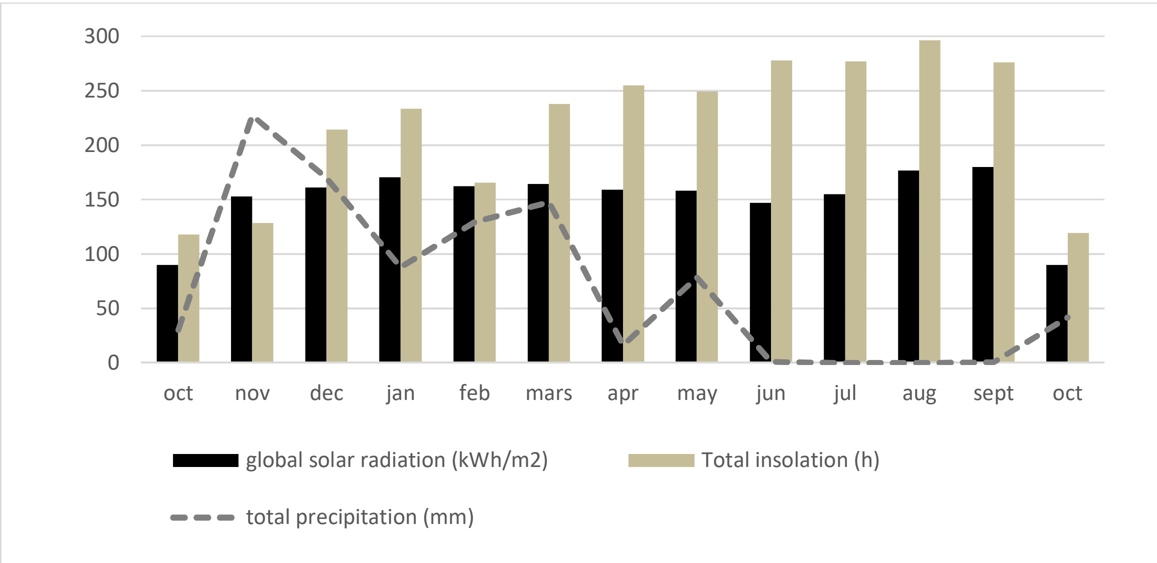


Figure 1 - Estimated global solar radiation and measured total insolation and total precipitation Climate conditions during geomembrane exposure.

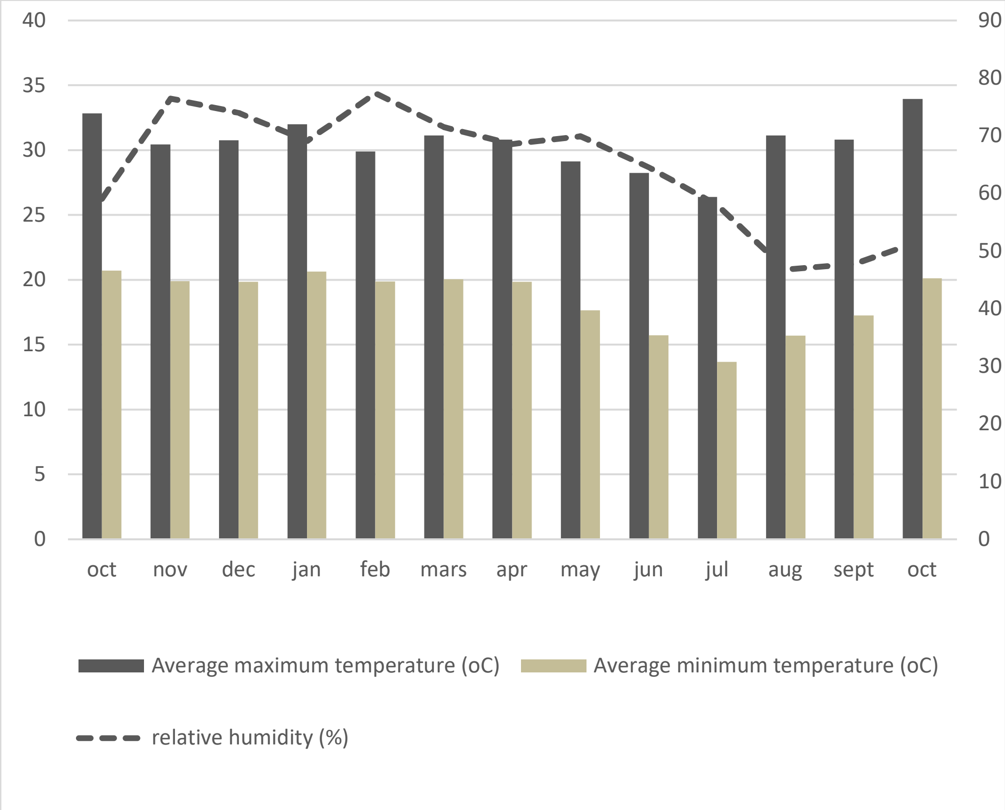


Figure 2 – Average temperatures and relative humidity during geomembrane exposure.

Assuming that the utraviolet radiation correspond to 7.5% of the global solar radiation, the estimated UV radiation on the exposed part of the sample is 496 MJ/m^2 while the part submersed during 7 months was submitted to an estimated UV radiation of 214 MJ/m^2. Minimum temperatures were registered in July (average 13,7ºC) and the average maximum temperatures range from 29 to 34 ºC.

3.2.2 Effluent conditions

As mentioned before, this geomembrane received the effluent from leach tailings during approximately 7 months, from January to July 2017. Significant amounts of copper, cadmium, arsenic, cyanide, phosphorous and sulfate were presented in the liquid flowing over the sample. Table 2 presents some properties of the leachate examined through this period .

Table 2 - Effluent average properties from January to July 2017

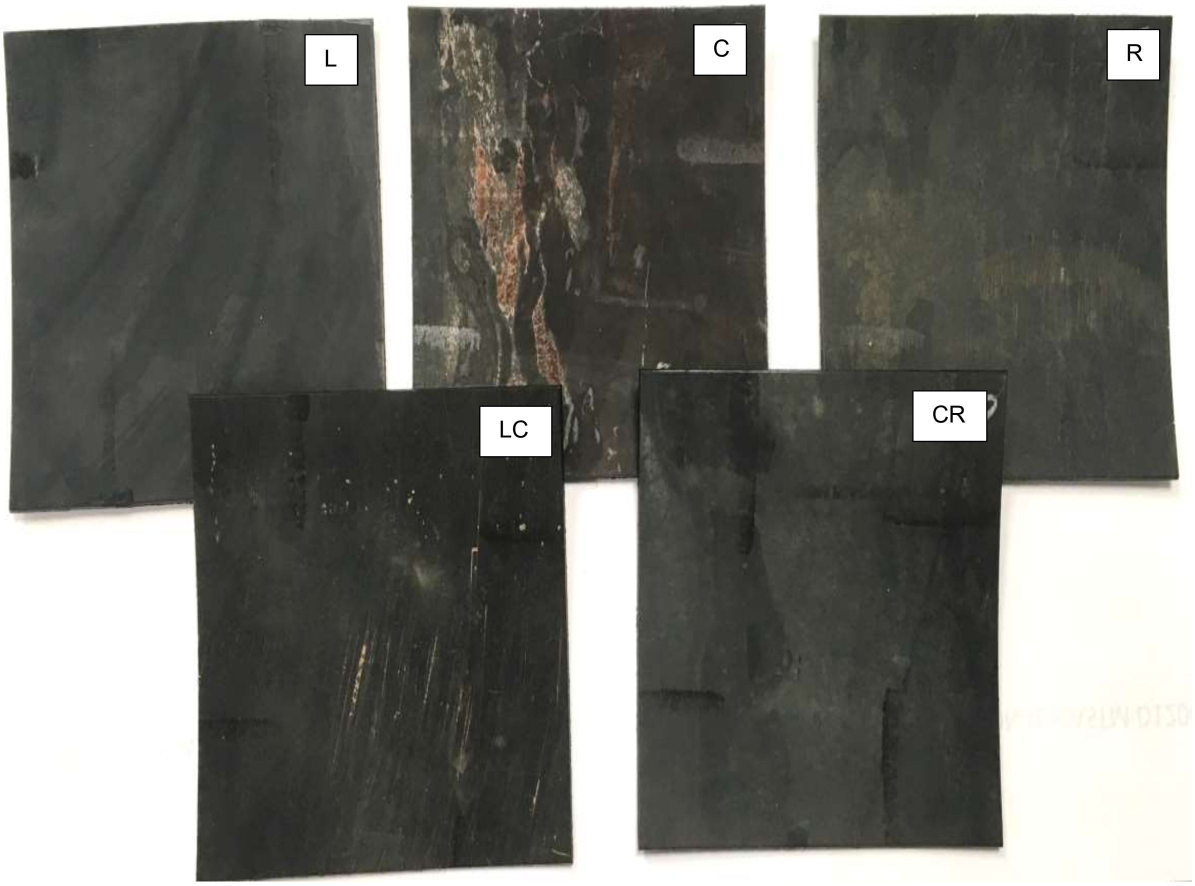
parameter	unity	Average value
pH	-	7.65
Temperature	(°C)	25.7
Eletrical condutivity	(µS/cm)	6470
Dissolved Oxigen	(mg OD/L)	5.7
Turbidity	(NTU)	2.34
Dissolved solids	mg/L	2617
Suspended solids	mg/L	33.8

4. TESTS

4.1 Sample characteristics

The exhumed sample was sent to the laboratory with no preliminary treatment, conserving the soil and other eventual particles that were present in the field. Upon arrival at the laboratory, the sample was washed under running water.

Five subsamples were chosen for the tests conducted in this phase of the research. Figure 3 illustrates the relative position and the apparent conditions of each subsample. It is possible to observe that the central part (C) presents some incrustations and subsample ME presented some kind of scratches.



Key:
L – left   C – center   R – right   LC – between left and center   CR – between center and right

Figure 3 - Subsamples collected for tests.

Table 3 resumes the results of the tests conducted in this phase of the analysis. Only the strength and elongation at break presented values slightly below the required.

Table 3 - Exhumed sample properties.

Property	Method	Unit	Minimal value	Maximal value	Mean value	Minimum requirements
Nominal thickness	ASTM D5199	mm	1.52	1.58	1.56	>1.5
Geomembrane density	ASTM D792	g/cm³	0.95	0.97	0.96	>0.940
Strength at yield MD direction	ASTM D 6693	kN/m	27.3	28.3	27.7	>22
Strength at yield CMD direction	ASTM D 6693	kN/m	26.3	29.0	27.7	>22
Strength at break MD direction	ASTM D 6693	kN/m	38.7	48.0	43.2	>40
Strength at break CMD direction	ASTM D 6693	kN/m	32.2	46.7	39.4	>40
Elongation at break MD direction	ASTM D 6693	%	668	732	709	>700
Elongation at break CMD direction	ASTM D 6693	%	587	757	683	>700
Tear resistance MD direction	ASTM D 1004	N	262	306	286	>187
Tear resistance CMD direction	ASTM D 1004	N	266	319	291	>187
Puncture resistance	ASTM D 4833	N	697	712	704	>480

Figure 4 presents the percentage of the retained property for thickness, density, tear resistance and puncture resistance, considering the subsample position . The flow direction on the extruder matches the CMD direction of the panel. Tear resistance presents greater variability, with the lowest observed value equal to 85%.

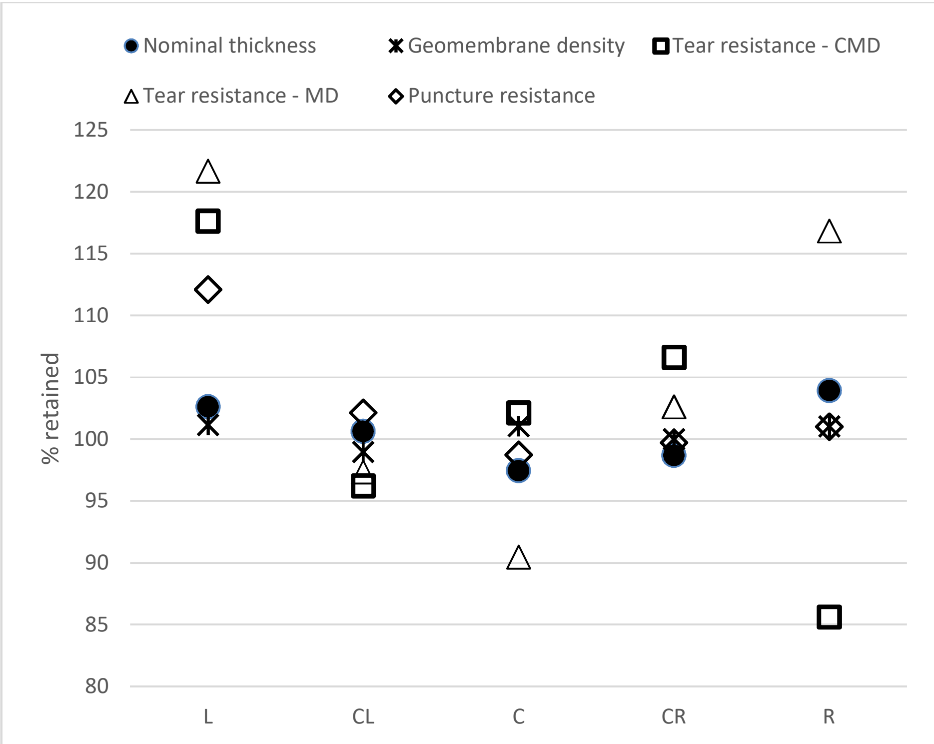


Figure 4 - Retained properties considering the subsample position - thickness, density, tear resistance and puncture resistance.

Figure 5 presents the percentage of the retained tensiile strength considering the subsample position. It can be observed that only the strength at break presents values below 75%.

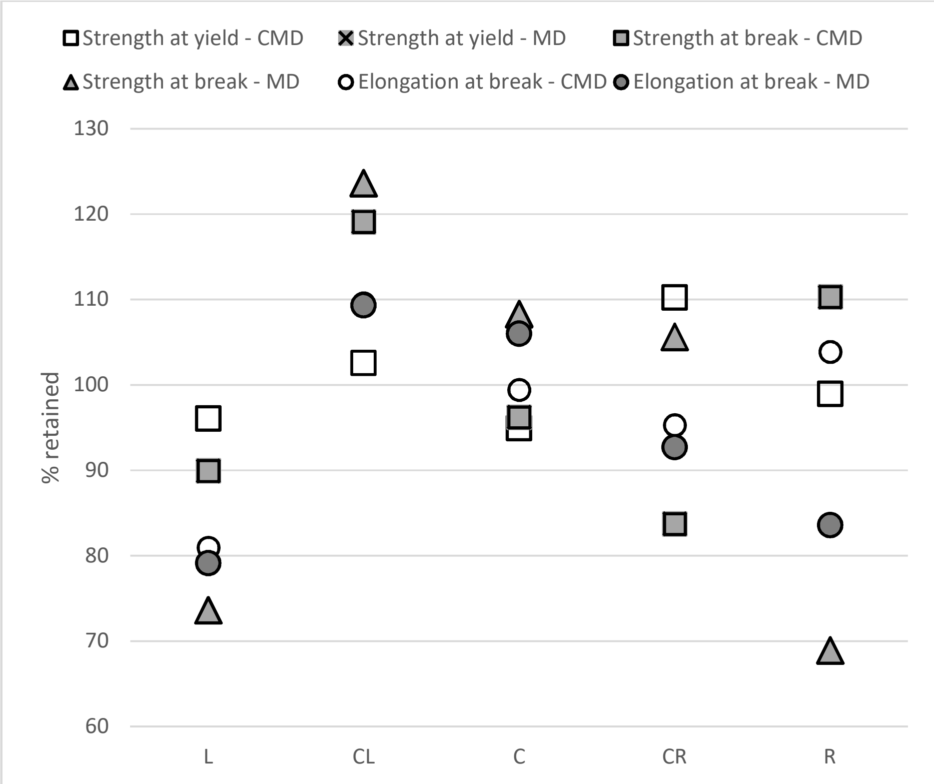


Figure 5 - Retained tensle strength considering the subsample position.

5. CONCLUSIONS

Based on results of physical and mechanical properties, the present paper evaluated the effects of environmental exposure on a high-density polyethylene (HDPE) geomembrane panel used along a leach tailings facility. The panel was exhumed after 12 months of open-air and intermittent liquid exposure, which highlights the fact that UV degradation and the contact with chemicals were the dominant degradation mechanism.

Yield strength has been retained over that period. At break, however, material strength underwent relatively higher variations (up to 12%). Similar changes were observed for break elongation. As expected, subsample situated in lateral parts, who received the highest intensity of UV radiation, showed the highest reductions in resistance.

After a year of exposition some parameters presented increased values. Chemical reactions, UV exposure, high temperature and the stiffness that occurs with aging may explain the observed variations, but require broader analyzes of the sample studied. Quantitative correlations between changes in mechanical properties, macro and microstructural characteristics of the polymer and the synergistic effects of UV and chemical degradation are being analyzed and will be the subject of future publications.

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