Short Term Durability and Performance of Bituminous Geomembranes with Respect to Temperature

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ABSTRACT

The purpose of this research is to investigate the performance of Bituminous Geomembranes (BGMs) over a wide range of temperatures to determine the short-term viability. Bituminous geomembranes are an alternative style of geomembrane barrier for use in landfills, lagoons, waste covers, and various other engineering applications that require an impermeable layer. Standard geomembranes (GMs) used in geotechnical practices can be composed of a wide variety of polymers including high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), polyvinyl chloride (PVC), polypropylene (PP), or ethylene propylene diene terpolymer (EPDM). Each of these polymers has its own set of physical and chemical properties which are favourable for different applications. Peer-reviewed research has been conducted on standard polymer geomembranes, however the same cannot be said for BGMs.

There are advantages to bituminous over polymeric GMs, chiefly, high strength, elongation, puncture resistance and high soil interface shear resistance. Underwater installation is made easier by the fact that BGMs are denser than water and most installations benefit from the limited tendency for wrinkling when exposed to thermal and solar radiation. However, the lack of public peer-reviewed data does add some uncertainty for designers considering using BGMs for barrier systems. This paper presents results of modified index tests of BGM puncture at various temperatures.

RÉSUMÉ

Le but de cette recherche est d'étudier la performance des géomembranes bitumineuses (BGM) sur une large gamme de températures afin de déterminer leur viabilité. Les géomembranes bitumineuses sont un style alternatif de barrière géomembranaire à utiliser dans les décharges, les lagunes, les couvertures de déchets et diverses autres applications d'ingénierie qui nécessitent une couche imperméable. Les géomembranes standard (GM) utilisées dans les pratiques géotechniques peuvent être composées d'une grande variété de polymères, y compris le polyéthylène haute densité (HDPE), le polyéthylène linéaire basse densité (LLDPE), le polychlorure de vinyle (PVC), le polypropylène (PP) ou l'éthylène propylène terpolymère de diène (EPDM). Chacun de ces polymères a son propre ensemble de propriétés physiques et chimiques qui sont favorables pour différentes applications. Des recherches évaluées par des pairs ont été menées sur des géomembranes polymères standard, mais on ne peut pas en dire autant des BGM.

Les GM bitumineux présentent des avantages par rapport aux GM polymères, principalement une résistance élevée, un allongement, une résistance à la perforation et une résistance élevée au cisaillement de l'interface du sol. L'installation sous l'eau est facilitée par le fait que la BGM est plus dense que l'eau et la plupart des installations bénéficient de la tendance limitée au froissement lorsqu'elles sont exposées au rayonnement thermique et solaire. Cependant, le manque de données publiques évaluées par des pairs ajoute une certaine incertitude pour les concepteurs qui envisagent d'utiliser des BGM. Cet article présente les résultats préliminaires de la modélisation physique («test de performance ») des dommages BGM à différentes températures.

1 INTRODUCTION

In general, bituminous geomembranes lack credible sources of data to confirm manufacturer specifications. There have been small amounts of research being undertaken by different institutions, but the available data is still very minimal. There is a variety of ongoing research at Queen’s University in Ontario by M. Clinton and K. Rowe (Clinton and Rowe 2017) involving leakage and puncture of BGMs. In a semi-arid climate like Saskatchewan’s, where temperatures can vary by more than 60°C between seasons, the performance of BGMs under a variety of temperatures can be deemed important in addition to regular leakage and loading performance.

Geomembranes are a non-porous media, meaning that there are no void spaces present within the material. However, fluid transport still occurs through the material at the molecular level via diffusion (Lambert et al. 2000). Driving forces of this diffusion include: concentration, temperature gradients, and hydraulic gradients (Touze-foltz et al. 2015).

BGMs typically consist of a core layer of a non-woven geotextile that has been impregnated with a waterproof bituminous binder, with a surface treatment to finish the product (Touze-Foltz and Farcas, 2017). The treatment product in modern BGMs is typically an elastomer like Styrene-Butadiene-Styrene (SBS). These are referred to as elastomeric BGMs. Elastomeric BGMs have low temperature brittleness ranges of -20°C to -30°C, maximum strain of roughly 10%, and a maximum break elongation of around 1500% (Touze-foltz et al. 2015). The data presented in this paper are preliminary test results, with larger scales and in-depth tests to follow. These data still provide insight into how variation in temperature influences BGM performance, specifically their resistance to puncture.

2 MATERIALS & METHODS

2.1 Selection of Bituminous Geomembranes (BGMs)

In the testing performed, two types of Coletanche elastic elastomeric BGMs were considered. The samples are the ES2 and ES4 variations. These samples were selected because they are two of the more popular products used and fit the average properties of the range of ES products (Axter Coletanche Inc. 2020).

The following composition and technical specifications in tables 1 and 2 come from the manufacturer provided technical sheet (Axter Coletanche Inc. 2009a) for ES2, while tables 3 and 4 take information from the ES4 technical sheet (Axter Coletanche Inc. 2009b).

2.1.1 ES2 Characteristics

The ES2 is composed of 5 materials. The material composition is shown in Table 1.

Table 1. Composition of ES2

Material	Value (g/m^2)	Purpose
Glass Mat	50	Reinforcement
Non-woven Geotextile	250	Reinforcement
Elastomeric SBS	4300	Binder
Sand	200	Surface Finish
Polyester Anti-root film	15	Surface Finish

Select technical specifications of the Coletanche ES2 BGM provided by can be seen below in Table 2.

Table 2. Technical Specs of ES2

Characteristic	Value	Units
Thickness	4.0	mm
Surface Mass	4.85	kg/m^2
Tearing Res. (MD/XD)	825/700	N
Max Tensile Str. (MD/XD)[1]	27/24	kN/m
Elongation (MD/XD)[1]	60/60	%
Static Puncture Res.[2]	530	N

[1] As per ASTM D 7275
[2] As per ASTM D 4833

2.1.2 ES4 Characteristics

The ES4 is also composed of 5 materials. The material composition is shown in Table 3.

Table 3. Composition of ES4

Material	Value (g/m^2)	Purpose
Glass Mat	50	Reinforcement
Non-woven Geotextile	400	Reinforcement
Elastomeric SBS	5400	Binder
Sand	200	Surface Finish
Polyester Anti-root film	15	Surface Finish

Select technical specifications of the Coletanche ES4 BGM provided by can be seen in Table 4.

Table 4. Technical Specs of ES4

Characteristic	Value	Units
Thickness	5.60	mm
Surface Mass	6.40	kg/m^2
Tearing Res. (MD/XD)	1225/1025	N
Max Tensile Str. (MD/XD)[1]	39/31	kN/m
Elongation (MD/XD)[1]	60/60	%
Static Puncture Res.[2]	650	N

[1] As per ASTM D 7275
[2] As per ASTM D 4833

2.1.3 Sample Photos

Test samples are 11 x 11 cm (+- 0.5cm) with 6 punctures used for mounting them in place during puncture. Figure 1 shows side and top views of the (a) ES2 and (b) ES4 samples which shows the difference in thickness between the two sample types.

a)

b)

Figure 1. Photos of a) ES2 and b) ES4 test samples

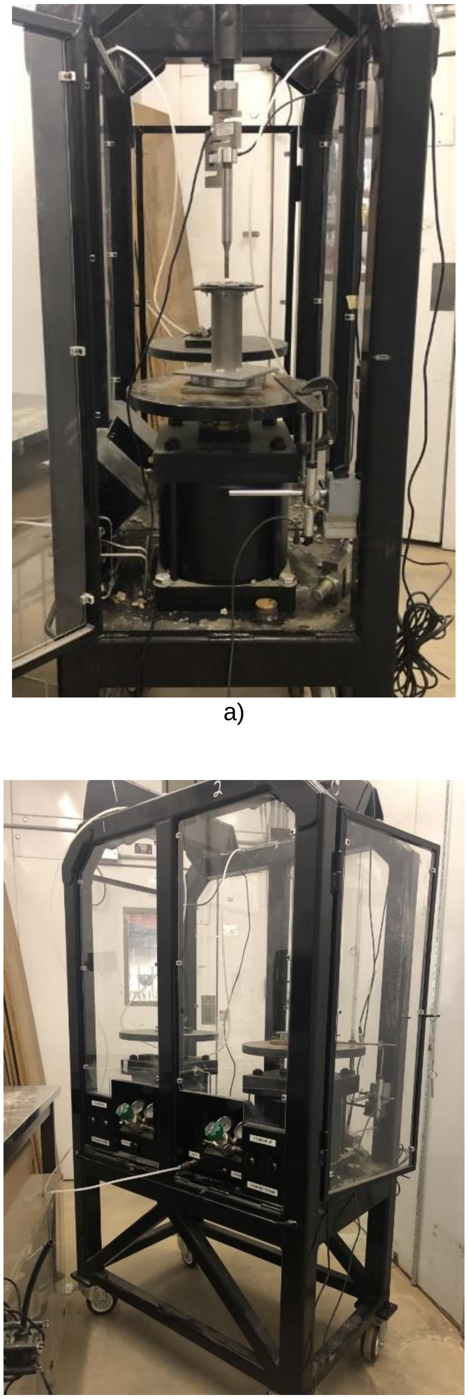
2.2 Testing Method

The method used in the initial stages of temperature dependance testing was the ASTM D 4833, used for evaluating Geomembrane puncture resistance. The ASTM procedure was followed for both the ES2 and ES4 products, and was performed at different temperature increments of 0°C, 5°C, 10°C, 20°C, and 30°C.

2.3 Testing Apparatus

2.3.1 Pneumatic Cylinder Frame

Figure 2 shows each of the key components of the apparatus. The main testing apparatus is a custom 10 in. air cylinder frame. The frame has an operating pressure of roughly 250 psi which corresponds to roughly 87 kN of force. The frame has an electronic pressure transducer allowing for the airflow to be changed to match the required displacement rates or loads. For this experiment, a displacement rate of 300mm/min (ASTM D 4833). was required. Using the transducer to adjust the airflow, the required displacement rate was reached within the allotted +/- 10 mm/min. After each temperature change, the speed was recalibrated to account for any minor changes caused by the change in air temperature. The apparatus is fitted with a load cell to measure the applied load on the BGM, and a linear variable differential transformer (LVDT) to measure the displacement of the plate. The system is connected to a custom data logger that logs data inputs at specified time intervals. This was set to every 0.1s for these tests. Although using a pneumatic cylinder has disadvantages when compared to hydraulic units, being able to move the frame into the climate chamber was more important for the purposes of this research.



a)

b)

Figure 2. Air cylinder frame (a) with experimental setup shown (LVDT on lower right, mounted to frame, load cell at top) and (b) the frame with the controls present.

2.3.2 ASTM Puncture Assembly

The second piece of equipment used in this testing was the puncture apparatus specified by ASTM D 4833 (2010). The setup consists of two pieces: the probe used for puncture, and the mounting frame used to hold the BGM sample.

The probe consists of a machined rod base, beveled into a 50mm long, 8mm diameter tip with a 0.8mm, 45° chamfer to the tip. The probe also has a threaded base to allow it to be connected to the load cell used in the tests.

Figure 3 shows each aspect of this setup below.

The base of the apparatus consists of a hollow cylindrical body welded to a base plate for stability. Attached to the top of the cylinder is a 4mm thick, 100mm diameter annulus with a 37mm diameter opening in the center. Equally spaced around the disc on a 45mm diameter placement are 6 8mm machined holes used to bolt the BGM in place. A second loose annulus with identical dimensions is mounted on top of the BGM to secure it in place.

a)

b)

Figure 3. a) Showing BGM mounted with secondary disc bolted in place, and b) puncturing probe next to side profile of mount

2.4 Testing Procedure

2.4.1 Testing Preparation

In preparation for the tests, 3 to 4 samples of each ES2 and ES4 were cut into 11cm x 11cm squares, and pre-drilled with holes to align with the bolt pattern of the testing assembly, using the upper mount of the assembly as a frame. The samples were then left to equilibrate inside the main climate chambers for 24 hours at the test temperature.

The temperature was controlled during testing using walk-in climate chambers available in the facility at the U of S. The chambers are large enough for the testing apparatus to be set up inside, allowing for the entire setup to be at the desired temperature. It takes a substantial amount of time for the temperature in the chamber to equilibrate at a new setting, therefore the chambers were allowed 24 hours to adjust to the new temperature requirement. There were also multiple thermometers in place to ensure the correct temperature was reached, both integrated into the climate chamber unit, and mounted inside the chamber independently.

2.4.2 Testing

Tests were performed at 0°C, 5°C, 10°C, 20°C, and 30°C. Once the chamber had reached the desired temperature, and the BGM samples equilibrated to the room, testing began. A single sample was mounted in the assembly, the valves on the air cylinder control were opened, and the mount was pressed into the probe until puncture was established. The force and displacement were recorded every 0.1s as the test. After each test the data was analyzed to confirm that the equipment properly recorded the data. This process was then repeated until each sample was punctured exactly one time. After all the samples were tested at each temperature, the temperature setting was set to the next temperature to be tested, let sit for 24 hours to equilibrate, and then the steps were repeated.

3 RESULTS & DISCUSSION

3.1 ES2 Results & Discussion

After running 3-4 tests on each product at each temperature range, both peak and average puncture resistance were recorded.

In addition to the peak values at each temperature increment, a plot showing the average response of the ES2 samples is shown in Figure 4. It is worth noting that for Figure 4 and Figure 5, noise in the data post-rupture is caused by allowing data to be logged for slightly different durations after puncture has been produced and does not impact the force required for puncture. Based on Figure 4, there was no visible difference between the response of the ES2 samples at most temperatures. However, at 30°C the average puncture resistance of the material was significantly lower at around 230 N, while the rest of the trials sat around 370 N puncture resistance. Though the required force to puncture the BGM was significantly lower at 30°C, the displacement required to initiate that puncture was still similar.

The data presented in Table 5 shows the peak responses of the ES2 samples at each temperature. Like the average responses at each temperature, 0-20°C have similar peak response values in puncture resistance, with the 30°C response being slightly lower.

When it comes to peak displacement responses for the ES2 samples, the 0-10°C trials all showed similar peak displacement values at puncture of around 25 mm, while the 20-30°C reached peak displacements of around 34 mm.

Table 5. Peak Values of ES2 Puncture Testing

Temperature (°C)	Puncture Res. (N)	Displacement (mm)
0	426.649	24.665
5	425.632	25.613
10	392.058	25.431
20	468.806	34.516
30	337.347	33.338

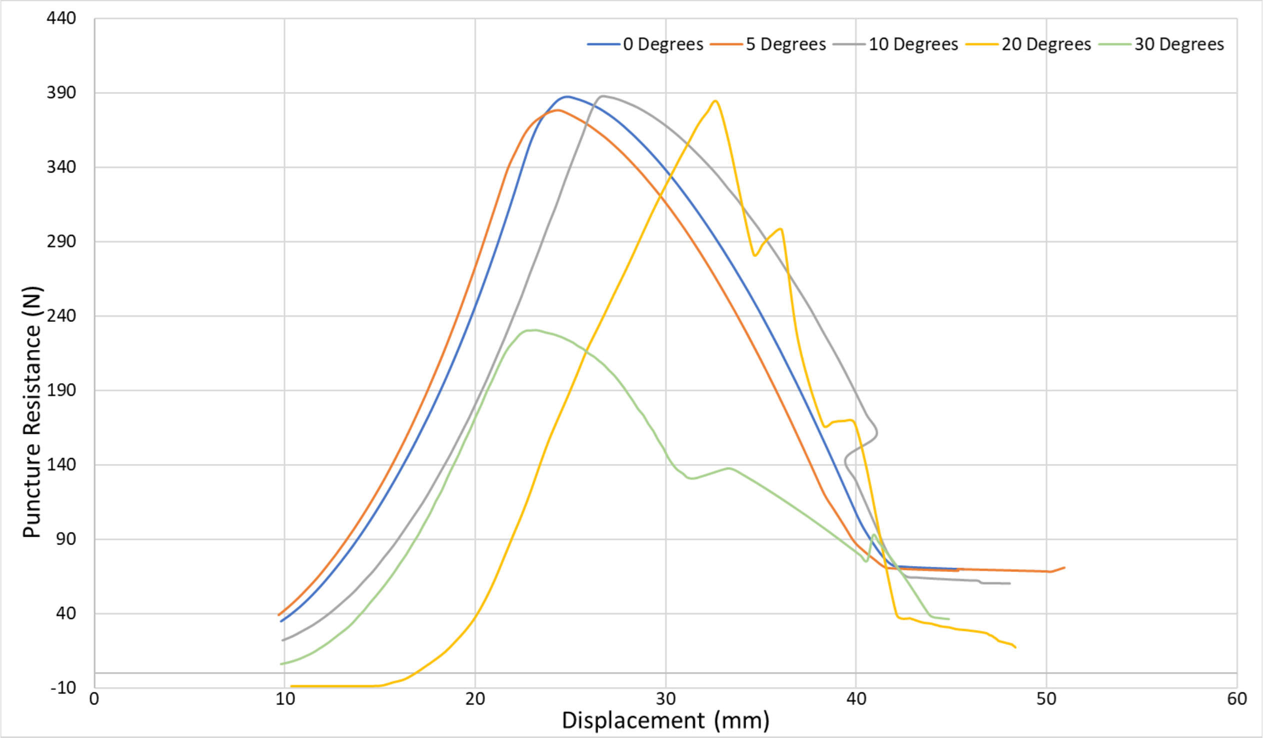


Figure 4. ES2 Average Responses of Puncture Resistance Vs Displacement w/ Temperature Variation

3.2 ES4 Results and Discussion

Similarly, to the ES2 tests, 3 to 4 tests were conducted on the ES4 product at each temperature. The average and peak puncture resistance, and displacements were recorded at each temperature and subsequently analyzed. Figure 5 shows the plot of average response of puncture resistance versus displacement (the post-rupture noise in the data is like that of Figure 4).

The data shown in Figure 5 follows similar trends compared to that of the ES2 responses, however there is a slightly more noticeable trend than seen in the ES2 trials.

Table 6. Peak Values of ES4 Puncture Testing

Temperature (°C)	Puncture Res. (N)	Displacement (mm)
0	731.67	23.97
5	600.87	24.28
10	678.50	24.47
20	454.15	36.38
30	498.49	33.32

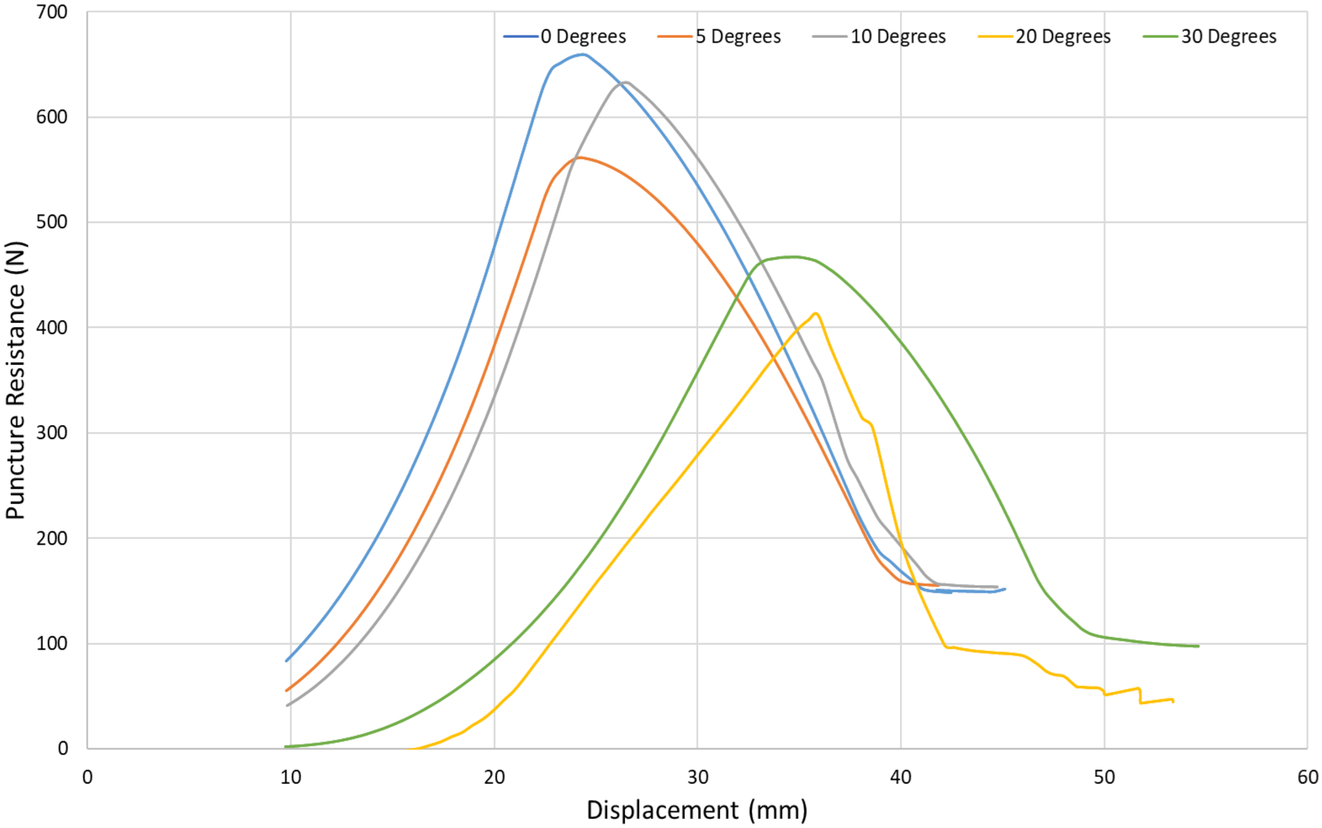


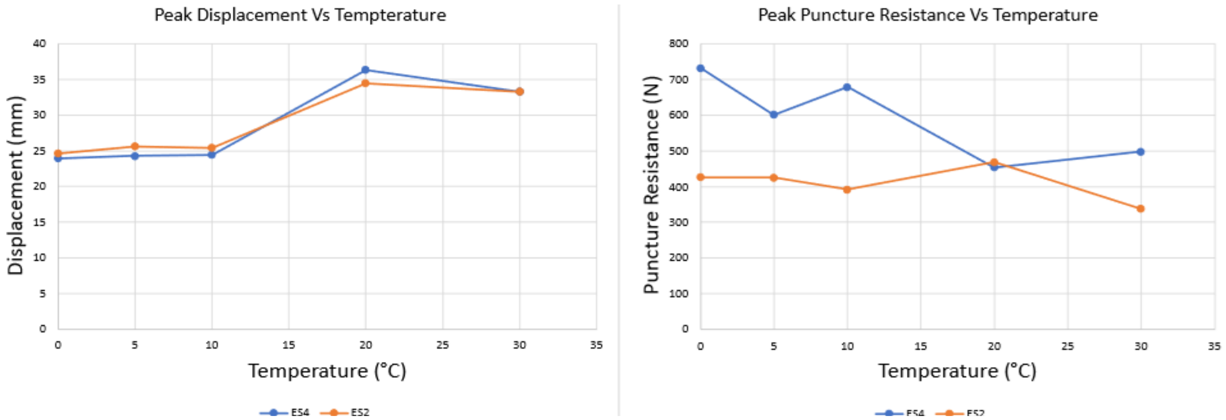
Figure 5. ES4 Average Responses of Puncture Resistance Vs Displacement w/ Temperature Variation

The three lower temperatures (0-10°C) all show higher resistance to puncture, and lower amounts of displacement before puncture occurs. For those three test temperatures the average puncture resistance is estimated to be around 550-650 N, with an average displacement of 25mm before rupture occurs.

For the two warmer test temperatures (20-30°C) the average puncture resistance is noticeably lower at around 400-450 N, with average displacements of roughly 35 mm before rupture. The peak responses of the ES4 product in each temperature trial are presented in Table 6, and again show similar trends to that of Table 5 and the ES2 product.

3.3 Trends in Peak Values

In general, the peak responses follow similar trends between the ES2 and ES4 products. Both exhibit higher resistance to puncture at lower temperatures, and larger displacements before puncture at higher temperatures Displacement versus temperature, and puncture resistance versus temperature are plotted in Figure 6. It is worth noting that when looking at peak puncture resistance versus temperature, the ES2 sample did not show as much variation as the ES4 samples. The ES2 sample peaks were much less scattered than that of the ES4 samples. The peak displacement did tend to increase with temperature in both products by nearly 30% from the low to high end.



a) b)

Figure 6. a) Peak Displacement and b) Peak Puncture Resistance versus Temperature

4 CONCLUSION

When evaluating the results of these tests, and by visual analysis during the test, it was observed that in warmer test environments (20-30°C), the samples had a much more ductile response to the puncture test with a nearly 30% increase in displacement over the lower temperature tests. Similarly, the materials responded in a more brittle manner when tested at lower temperatures. Higher forces were required for puncture at low temperatures, especially in the case of ES4.
Increasing temperature also correlates with lower peak puncture resistance values for both tests. It should also be noted that the average puncture resistances found form this testing fell below the manufacturer stated puncture results from the same ASTM standard in most cases presented. Based on these results, a positive correlation can be drawn between increases in temperature and displacement required for puncture, and a negative correlation between temperature and force required for puncture of the BGMs.

5 FUTURE WORK

There are more tests planned for future work related to this project involving simulated landfill conditions under high loads with leakage introduced to the system. Additionally, the climate chambers currently available do not allow sub-zero temperatures, so walk-in freezer units are going to be used to run all tests mentioned in this paper, along with future work at temperatures down to -20°C.

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