A comparison of HDPE geomembranes for response to strains that may be associated with stress cracking

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ABSTRACT: A limitation with HDPE geomembranes is their susceptibility to stress cracking – a brittle failure below the yield point of the geomembrane. Applied stresses (particularly localised stress concentrations) and excessive strain may stimulate the development of stress cracks in HDPE geomembranes. These processes may occur relatively quickly if the antioxidants are depleted.

This paper compares HDPE geomembranes for their response to potential stress cracking strains. One of the geomembranes compared was manufactured using Polyethylene of Raised Temperature Resistance (PE-RT) resin. This resin gives higher stress crack resistance and greater tensile strength/elongation than some other resin formulations. The stress crack resistance for a 1.5 mm (60 mil) thickness of the PERT based HDPE geomembrane – also referred to as new HDPE geomembrane in this paper is three times more than that for a standard HDPE geomembrane that has material properties that meet the minimum GRI GM13 requirements – also referred to as a GRI GM13 spec geomembrane in this paper.

Large scale high pressure strain testing was completed on the new HDPE geomembrane and the GRI GM13 spec geomembrane in order to evaluate their response to localized strain from point loading that may be associated with stress cracking. The results show fewer localized strains across the geomembrane in comparison with a standard GRI GM13 spec HDPE geomembrane under similar loading conditions. The geomembranes are also being tested for stress cracking and retention of OIT and HP OIT after aqueous immersion of 180 degree dead-folds in concentrated brine solution. The large scale high pressure strain testing is discussed.

Keywords: HDPE geomembrane; stress crack resistance; OIT; HPOIT; large strains, puncture resistance; demanding service conditions, applied stresses, long term durability, UV resistance

1. INTRODUCTION

HDPE geomembranes are preferred on sites for their broad chemical resistance, mechanical performance, durability and cost effectiveness. However, not all HDPE geomembranes are created equal and the performance of HDPE geomembranes differ with the material properties – especially the mechanical and durability properties. The material properties of HDPE geomembranes depend on the base resin and the quality of stabilizers and additives in the formulation to enhance the performance of the geomembrane in service. Such additives and stabilizers include those for increasing stress crack resistance, tensile properties, puncture and strain resistance, UV resistance and retention of antioxidants.

Given the susceptibility of HDPE geomembranes to stress cracking – a brittle failure below the yield stress of the geomembrane, caused by a highly crystalline microstructure, it is important that HDPE geomembranes are made from resin with a high stress crack resistance, and that strains in the geomembrane on the field are kept below the limiting values for stress cracking. Typical limiting strains for preventing stress cracking in HDPE geomembranes are between 3 to 8% strains (Rowe and Sangam 2002; Peggs 2003; Peggs et al 2005; Scheirs 2009; Muller 2007). Peggs (2003) and Peggs et al (2005) recommend a maximum strain of 8% for HDPE geomembranes with a stress crack resistance > 1500 hours; and a maximum strain of 6% strain for those with stress crack resistance values < 1500 hours.

The material properties and the performance of HDPE geomembranes against potential stress cracking strains are compared in this paper. One of the HDPE geomembranes compared – also referred to as new HDPE geomembrane in this paper is made from PE-RT – Polyethylene of Raised Temperature Resistance base resin. Using the PE-RT resin, HDPE geomembranes with higher yield strength and elongation and higher stress crack resistance can be produced. The microstructure of PE-RT is obtained by controlling the mode of incorporation of co-monomer into the crystalline microstructure of the polymer and by optimizing the concentration of tie molecules in the polymer structure (see: Schramm and Jeruzal n.d.). The resin density of the PE-RT used in the production of the new HDPE geomembrane is 0.941 g/cm^3. In addition to the use of the PE-RT resin, the formulation for the new HDPE geomembrane also contains proprietary stabilizers and UV additives for enhanced longevity.

The index properties of the new HDPE geomembrane, the GRI GM13 spec geomembrane and those for "high performance" HDPE geomembranes available on the market were compared. Additionally, the response of the new HDPE geomembrane and the GRI GM13 spec geomembrane to strains that may be associated with stress cracking was evaluated from performance testing. One of the performance testing involved large scale high pressure loading to assess localised straining due to point loading. The other involved measuring the OIT and HPOIT after aqueous immersion of 180 degree dead-folds in concentrated brine solution. The large scale high pressure testing has been completed, while the immersion testing is ongoing.

The large scale high pressure testing was used to determine the distribution of localized strains in the geomembranes under applied loads and in contact with angular materials that may potentially induce stress cracking on the field. The response of the new HDPE geomembrane as well as that of a standard HDPE (GRI GM13 spec) geomembrane may be simply expressed as the percent of the total geomembrane surface area in which threshold limiting strains for stress cracking were exceeded. The methodology and equipment setup are described further in the next section.

2 EXPERIMENTAL

2.1 *Index testing*

This was completed as per the standard test methods in the GRI GM13 specification for HDPE geomembranes. The GRI GM13 sets the minimum values to be met for individual the material properties of HDPE geomembranes. The physical, mechanical and endurance properties of the new HDPE geomembrane were determined as per the GRI GM13 requirements. Samples from a standard GRI GM13 spec HDPE geomembrane were also tested for comparison. The testing was completed in-house, and also by independent third party geosynthetics laboratories (the TRI and GRI laboratories) – to verify the results obtained in-house.

Additionally, the material properties of the new HDPE geomembrane were compared with those classified as "high performance" HDPE geomembranes on the market to benchmark the performance of the various HDPE materials. The results for the "high performance" HDPE geomembranes were obtained from the published technical data sheets available on the manufacturers' websites.

2.2 *Large scale high pressure strain testing*

This was completed at the Geotechnical Research Laboratory at the University of Saskatchewan, Canada using a custom made large strain testing equipment. Testing was completed on the new HDPE geomembrane and the standard (GRI GM13 spec) materials and compacted Floral Till (Bjerrum 1972) was used as a subgrade in the testing (see: Table 1 for properties of the Floral Till).

Table 1: Properties of the subgrade Floral Till material

Property	**Values**
Liquid limit (%)	43
Plastic limit (%)	21
Optimum moisture content (%)	21
Maximum dry density (kg/m^3)	1630
Undrained shear strength (Su) achieved (kPa)	113

The subgrade sample was dried, crushed, mixed uniformly with water, divided into two 300 mm by 300 mm steel boxes and compacted. The moulding water content was 21.5 % for both samples in the boxes. The samples were compacted to a height of 100 mm using a standard Proctor hammer in three lifts of 270 blows per lift. The maximum dry density achieved was 1630 kg/m^3. A 0.02 mm thick sheet of polyethylene plastic wrap was placed on top of each compacted clay sample to prevent the clay from adhering to the geomembrane surface to allow for direct scanning of the deformed clay surface upon removal of the applied load. Similar studies in the literature placed lead sheets on the subgrade and scanned these to capture deformations (Tognon et al 2000; Rowe et al 2013; Brachman et al 2014).

Test samples, 300 mm by 300 mm in size, were cut from both the GRI GM13 spec standard material and the new HDPE geomembrane material. Each geomembrane sample was placed on the plastic wrap and compacted clay and uniform 38 mm crushed gravel was placed randomly on both geomembranes. Load was applied to each test cell simultaneously at a loading rate of 3kPa/min to a maximum load of 640 kPa. The final applied load was held for 96 hours and after this, the gravel was removed and geomembrane was inspected for puncture and deformations.

3 RESULTS

3.1 *Index testing*

Table 2 presents the properties of 60 mil thicknesses of the new HDPE geomembrane, a standard/GRI GM13 spec material and three “high performance” HDPE geomembranes from three manufacturers (denoted as M2, M3 and M4). The material properties of the new HDPE geomembrane exceed those for the GRI GM13 spec material and those for the “high performance” HDPE geomembranes for all the properties compared. The values from the in-house testing are slightly lower in comparison with the independent testing completed by the TRI and GRI laboratories because the in-house testing values are the minimum values obtained from the testing, while those for the independent testing are mean values.

Table 2: Index testing properties for the new HDPE geomembrane, a GRI GM 13 spec geomembrane and "high performance" HDPE geomembranes from three manufacturers – 60 mil (1.5 mm) thicknesses. (*DNT implies did not test)

Material Property	GRI GM13 Spec. (minimum values to be met)	New HDPE Smooth Results from in-house testing	New HDPE Smooth Results from 3rd Party Lab (GRI)	New HDPE Smooth Results from 3rd Party Lab (TRI)	"High Performance" HDPE Smooth (M2)	"High Performance" HDPE Smooth (M3)	"High Performance" HDPE Smooth (M4)
OIT (min.)	100	200	300	Ongoing	140	Not reported	160
HP - OIT (min.)	400	1000	DNT	Ongoing	Not reported	Not reported	800
Tensile Strength at Yield (kN/m)	22	26	29	32	23	22	23
Elongation at Yield (%)	12	14	15	19	13	12	13
Tear Resistance (N)	187	200	221	223	200	187	187
Puncture Resistance (N)	480	622	685	634	534	480	556
Stress Crack Resistance (SP-NCTL) (Hrs.)	500	1500	DNT	Ongoing	500	500	1000
Oven Aging - OIT Retained after 90 days (%)	55	Ongoing	DNT	Ongoing	Not reported	Not reported	Not reported
Oven Aging - HP-OIT retained after 90 days (%)	80	90	DNT	Ongoing	Not reported	Not reported	80
UV Resistance – HP-OIT retained after 1600 hrs. (%)	50	85	DNT	Ongoing	Not reported	Not reported	80

3.2 *The large scale high pressure strain testing*

No puncture was observed in both materials, but both had plastic deformations from localized strains (see Figure 1). The loading rate applied during the testing was fairly rapid, hence the deformations and strains in the geomembranes reflect undrained loading of the subgrade clay material. The localized strains may be greater than might be expected under field conditions where the vertical stress is built up slowly over a longer period and drained loading occurs.

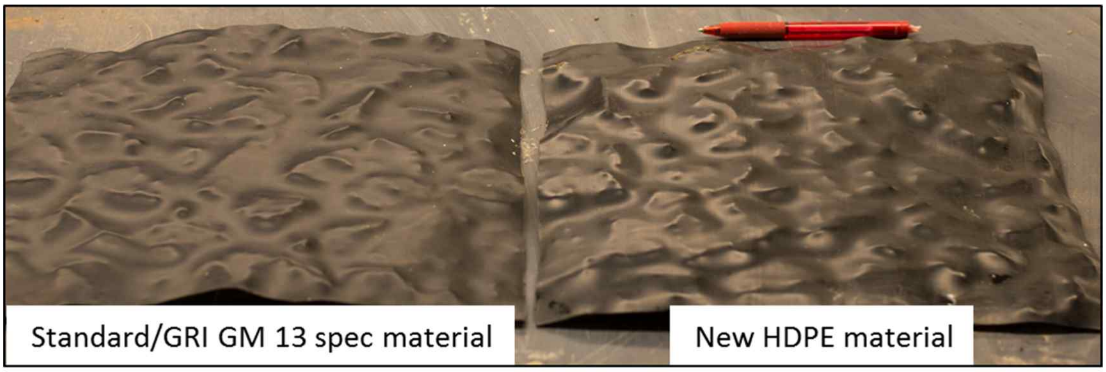

Figure 1. The deformed surfaces of the materials

To generate a map of the strains for a strain distribution curve, the clay surface was painted after removing the plastic sheet cover, and a photogrammetry procedure, as outlined by Marcotte & Fleming (2017), was used to create a three dimensional point cloud of the deformed surfaces clay surfaces. The procedure involved taking multiple photographs of the clay surface at different locations and using computer software to triangulate and determine elevations.

An image of the clay surface with reference scale bar (adapted from Porter, 2016) is presented in Figure 2 and a computer generated mesh from the photogrammetry procedure is presented in Figure 3.

Figure 2. The painted clay surface with scale bar

Figure 3. Digital point cloud model of the clay surface – the new HDPE geomembrane shown

Strains were calculated using a combination of global and localized strains, as outlined by Tognon et al (2000). The point cloud model was then evaluated using a modified version of the grid scanning method described by Hornsey & Wishaw (2012), to include the global strain used by Tognon et al (2000). The overall strains in the geomembranes were mapped (Figure 4) and used to generate strain area distribution plots, as described by Hornsey and Wishaw (2012) (see Figure 5)

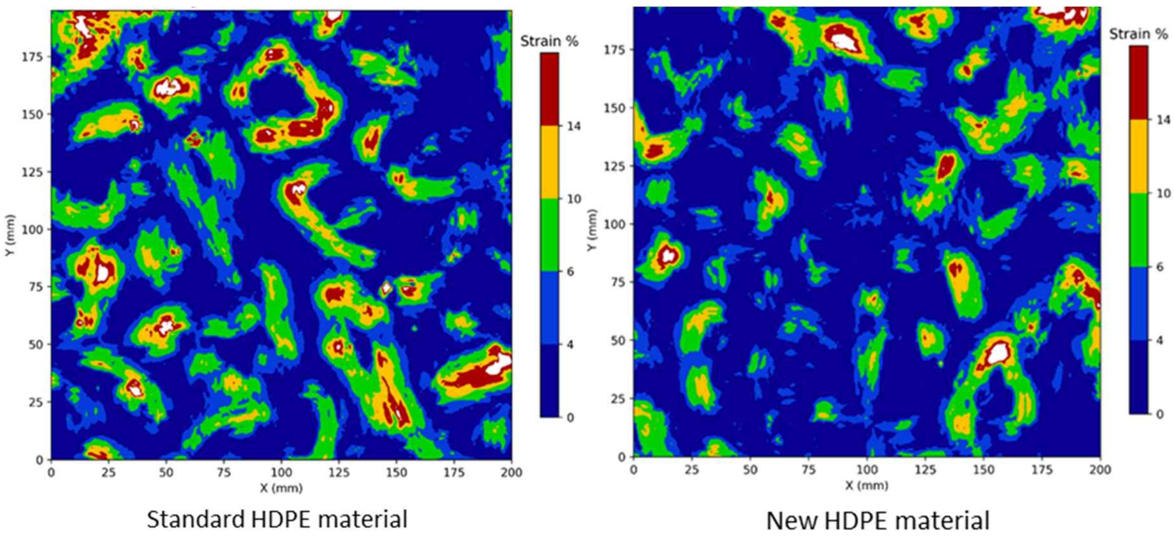

Figure 4. Strain mapping of the geomembranes for generating strain area distribution plots

Strain area distributions offer a visual comparison of each geomembrane. The strain area distribution approach is analogous to a particle size distribution plot, where the percentage finer than certain particle dimensions are plotted. Using the Hornsey and Wishaw approach, strain area distribution for the geomembranes were represented as the percent of the total geomembrane area in which a threshold strain was exceeded (see Figure 5).

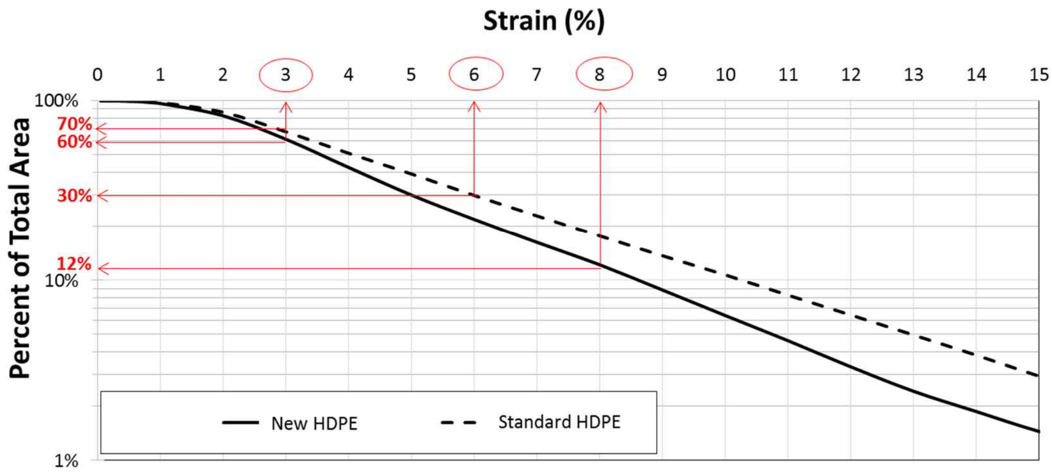

Figure 5. The strain area distribution plots for the new HDPE geomembrane and the standard GRI GM 13 geomembrane

Figure 5 shows that generally, more percentage area of the standard GRI GM13 spec HDPE geomembrane exceeded a given threshold strain than the new HDPE material. A correlation of the results for the geomembranes with the typical threshold strains of 3 to 8% for stress cracking in HDPE geomembranes is presented in Table 2

Table 2: Comparing stress cracking strains in the new HDPE geomembranes and a standard GRI GM13 spec HDPE

Threshold strain for stress cracking (%)	Percent of total area exceeding threshold strain (%)	
	New HDPE geomembrane	Standard (GRI GM13 spec) HDPE geomembrane
3	60	70
6	20	30
8	12	Not included in the comparison since 8% strain is not recommended for HDPE geomembranes with a stress crack resistance <1500 hours (Peggs, 2003, Peggs et al, 2005)

4 DISCUSSIONS

All things being equal, for high loading with point loads induced by gravel and no protection layer in the large strain testing, the strain area distribution of the new HDPE geomembrane was lower than the GRI GM13 spec geomembrane. In other words, the new HDPE geomembrane appeared to have stiffened (at least slightly) the response of the system, resulting in fewer strains across the geomembrane than in the GRI GM13 spec geomembrane.

Additionally, for a threshold strain of 8% for stress cracking for the new HDPE geomembrane, as opposed to 6% for the GRI GM13 spec material, there is a decrease by a factor of 2.5 in the proportion of the new HDPE geomembrane over which the threshold strain value is exceeded. A tentative conclusion may be reached that the new HDPE geomembrane may exhibit a lower frequency of localised straining at levels associated with potential stress cracking.

Increased service life may also be achieved based on relatively high values of OIT and HP-OIT. The higher values of OIT, HPOIT and UV resistance of the new HDPE geomembrane may be beneficial for long term performance as they may result in reduced frequency of replacement or maintenance of the geomembrane following prolonged exposure to UV light and exposure to antioxidant depleting events.

5 CONCLUSIONS

A new HDPE geomembrane with enhanced stress crack resistance, mechanical and durability properties provided by PE-RT resin in combination with proprietary additives and stabilizers has been presented. Some aspects of the material properties of the geomembrane have been discussed. Aspects discussed include (1) potential for increased threshold strains in the geomembrane from 6% to 8% given a stress crack resistance of 1500 hours, (2) fewer localized strains across the geomembrane relative to a standard GRI GM13 spec HDPE geomembrane under similar point loading conditions, and (3) a reduced frequency of the occurrence of potential stress cracking strains in the new HDPE geomembrane relative to a standard GRI GM13 spec HDPE geomembrane.

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