TENSILE RESISTANCE OF GEOMEMBRANES FOR HIGH TEMPERATURE APPLICATIONS

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ABSTRACT
For many applications, geomembranes are exposed to high temperatures for varying periods of time. If there is tension in the geomembrane when heat is applied the material may be at risk of failure due to creep rupture. High temperature applications include geomembranes exposed on vertical walls, on steep slopes, in landfills, in waste lagoons, or in the secondary containment of hot liquids. Depending on the polymer's intrinsic thermal properties, softening can cause a significant loss in tensile strength even at temperatures well below the melting point.

The high temperature tensile strength of several geomembranes made from various types of polymers is compared in this paper. A number of geomembrane materials that are specifically used in high temperature applications were tested including high temperature polyvinyl chloride (PVC), polytetrafluoroethylene (PTFE), and high temperature high density polyethylene (HDPE) materials. A fabric-supported high temperature PVC was included to show the difference between fabric-supported and unsupported geomembranes. A number of control samples were also included.

RESUMÉ
Pour plusieurs applications, les géomembranes sont exposés à des températures élevées pour des périodes d'exposition variables. Lorsque la gomembrane est soumise à une contrainte en tension avec source de chaleur, le matériau pourrait risquer de rompre sous l'effet de fluage. Les applications à haute température comprennent les géomembranes exposées sur murs verticaux, sur pentes élevées, sur site d'enfouissement, bassins de rétention, ou bien dans le confinement de liquides chauds. Selon les propriétés intrinsèques du polymère, le ramollissement peut causer une perte significative en résistance à la tension, à des températures bien en-dessous du point de fusion.

La résistance en tension à haute température de plusieurs géomembranes fabriquées à partir de types de polymères différents est comparée dans cet article. Plusieurs matériaux de géomembrane qui sont spécifiquement utilisés pour des applications à haute température ont été mis à l'essai, incluant le polyvinyl chloré (PVC), poly-tétrafluoroéthylène (PTFE), et le polyéthylène à haute densité pour haute températures (HDPE). Une géomembrane de PVC renforcée d'un support tissé a été inclus pour montrer la différence entre les membranes avec et sans renfort tissé. Quelques échantillons de contrôle y sont également inclus.

1 INTRODUCTION

There has been a lot of interest in higher temperature geomembranes in the past few years. One area of particular interest has been in the containment of flow-back liquids in the hydraulic fracturing industry. Over the past three years we have noticed an increase in requests for geomembranes to resist hotter temperatures. Another application for higher temperature geomembrane has been as a secondary containment liner under heated storage tanks (Mills, Martin 2008). In recent years we have seen an increase in the temperatures that need to be contained under heated tanks. This paper is part of a study of higher temperature geomembranes by Layfield in partnership with SAGEOS.

2 BACKGROUND

In geomembrane applications it has been common practice to move away from unsupported geomembranes when temperatures start to go beyond 60C. The normal behaviour of the polymers is that they lose strength when warm and if there are any forces on the material they will creep. This is particularly noticeable on steep slopes and in vertical walls in tank linings. As the temperature rises the material will lose tensile strength and begin to creep. This would result in thinning of the materials at the top of a tank or slope and if allowed to progress would result in a material failure. Fabric supported materials contain a woven scrim fabric (typically polyester) that would retain its strength at elevated temperatures. Supported geomembranes were often specified in steep slope or vertical applications.

In this paper, the physical effects of high temperatures on a geomembrane were studied, particularly by measuring its tensile properties. The goal was to determine the relationship between the temperature and the physical properties of the material.

3 MATERIALS

For the study, a variety of samples were selected, samples that have been used in the past for higher temperature service. Along with these samples, two control samples and two samples of new polyethylene materials for higher temperature service were added, for a total of eight materials.

The first materials selected were materials that had been investigated previously for high temperature service. In Mills and Martin (2008) they were identified as the PVC (polyvinyl chloride) alloys trade named HT 2000 and HAZGARD 5000HT. The HT 2000 PVC alloy is 0.75 mm (30 mil) thick, unsupported and blue in colour. The HAZGARD 5000HT is another type of PVC alloy and is 0.75 mm (30 mil) thick, fabric supported and red on one side and black on the other. These materials will be identified as PVC Alloy 1 (Blue) and PVC Alloy 2 (Red/Black supported) respectively. PVC and its alloys are good materials for higher temperature service. PVC has been used for many years in the wire and cable industry at elevated temperatures and PVC has a higher melting point that polyethylene materials. These PVC alloys have service temperatures in the 65C to 100C range (depending on the chemical contained).

The second type of material selected is trade named Teflon and is a polytetrafluoroethylene (PTFE) material. This material is black in colour and the sample tested was 0.75 mm (30 mil) thick. PTFE is often used as a material for seals in very high temperature applications and this particular material is rated to service temperatures up to 315C. It is exceptionally difficult to fabricate and install and is substantially more expensive than other geomembranes however its high temperature performance outstrips all other materials.

Three materials were included as control samples these materials are identified as a fortified version of a High Density Polyethylene (HDPE) geomembrane trade named HD 60 EX. This material is 1.5 mm (60 mil thick) and is black in colour and will be identified in this paper as HDPE. The next material is a fortified LLDPE (Linear Low Density Polyethylene) geomembrane material not yet commercial which is identified as EXP 1014. This material is 0.75 mm (30 mil) black and will be identified as LLDPE. The last control sample is our Enviro Liner 6060 material which is 1.5 mm (60 mil) white/black and will be identified in this paper as Polyolefin Alloy (white/black).

The last category of materials tested is called Polyethylene Raised Temperature (PERT). These are a new category of HDPE materials that have been introduced into hot water piping applications and are being adapted to geomembrane applications. There are two materials in this study, one made by Layfield which will be identified as PERT HDPE 1 and a second material manufactured by an offshore manufacturer identified as PERT HDPE 2. Both materials are 1.5 mm (60 mil) thick and are black in colour. PERT HDPE was originally developed for piping and is rated for continuous duty at 80C in piping service. The main purpose of our research project is an investigation of these PERT HDPE materials.

Table 1. Designation of materials.

Trade Name	Generic Description	Physical Description
High Temp 2000	PVC Alloy 1	30 mil, blue, unsupported
HAZGARD 5000	PVC Alloy 2	30 mil, Red/Black, supported
Teflon 30	PTFE	30 mil black, unsupported
EXP 1014	LLDPE	30 mil black, unsupported
Enviro Liner 6060	Polyolefin alloy	60 mil black/white, unsupported
High Density EX 60	Fortified HDPE	60 mil black, unsupported
HeatGard HD 60	PERT HDPE 1	60 mil black, unsupported
Non-Layfield	PERT	60 mil

PERT HDPE	HDPE 2	black, unsupported

4 TESTING

Tensile testing was done in accordance with ASTM D638 standard test method, using Type IV specimens and an extensometer for strain measurements. Each material was tensile tested in an environmental chamber at temperatures of -20°C, 23°C, 60°C, and 100°C. Samples were tested in machine direction.

Tensile testing was done using a Zwick Z050 allround round materials testing system, equipped with a temperature chamber and wedge-action grips. Strain rate was measured with a Zwick MultiXtens extensometer from an initial 25 mm gage length. Tests were conducted at a test speed of 250 mm/min. This test speed was selected to mimic at best the strain rate of PVC geomembranes, which are commonly tested per ASTM D882, at a strain rate of 10 (mm/mm)/min.

Another objective was to explore the limits of temperature to see if there was a temperature beyond which the materials were ineffective. Most of the polyethylene materials have a melting point that starts around 120°C however attempting tensile testing above 100°C was very difficult. In order to investigate temperatures above 100°C we also used the DMA apparatus.

A TA Instruments DMA Q800 was used, with tension film clamps. A temperature ramp was performed from 40°C to 150°C, under a sinusoidal oscillation strain of 25 μm at a frequency of 1 Hz, force was measured throughout the temperature ramp. Samples of 6.3 mm width by 33 mm long were tested and the storage modulus was estimated as a function of temperature.

5 RESULTS

Tensile strength was measured as function of temperature. Figure 1 shows the comparison of materials, points being measured between -20°C and 100°C. Because of its heat resistant reinforcement, the supported PVC has a superior resistance, with its resistance decreasing of less than 40% between -20°C and 100°C. On the other hand, all polyethylene materials are observed to have their resistance decrease by 2 to 3 times between 23 and 60°C, The PERT HDPE materials are slightly less weak than the other polyethylene materials in this range of temperature, while LLDPE is being the more influenced by temperature.

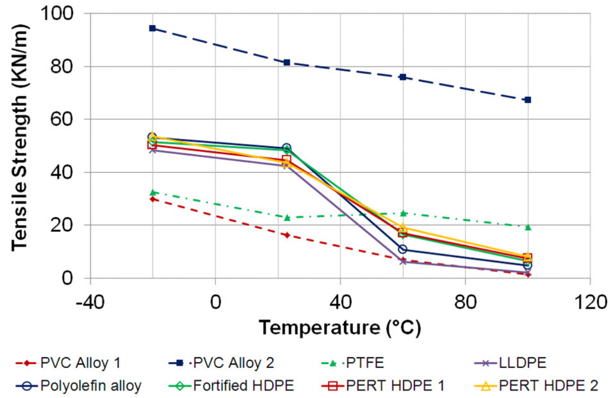

Figure 1. Effect of temperature on tensile strength.

As the temperature raise, an increase in elongation at yield is also observed. The polyolefin-based materials elongates similarly with temperature, a slightly lower elongation at yield is observed with PERT HDPEs, as pictured on Figure 2. However, the mode of deformation is quite changing as we approach 60°C, and the deformation becomes inelastic. Figure 3 shows individual tensile curves with temperature on the PERT HDPE 1, whereas Figure 4 shows the same relation with LLDPE with temperature. It shows a transition from an elastic mode of deformation to a ductile mode of deformation in the starting portion of the curve. Yield points were analyzed using the offset method of ASTM D638, when the maximum could not be clearly defined.

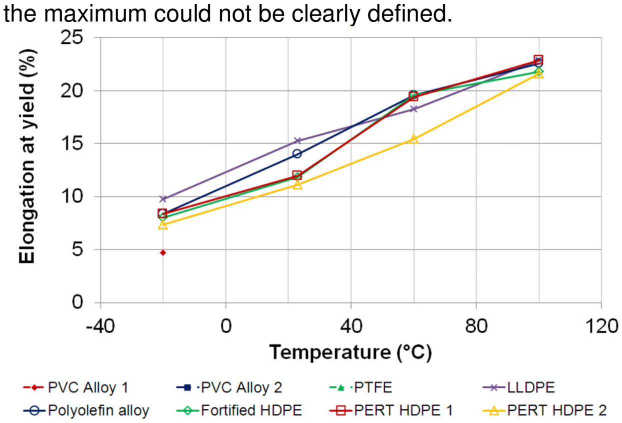

Figure 2. Effect of temperature on the elongation at yield of polyolefin-based materials.

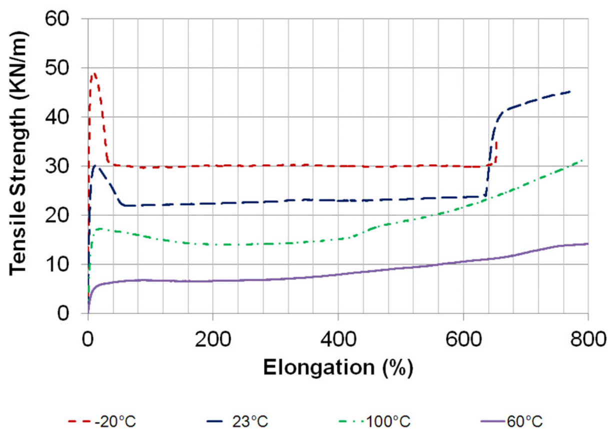

Figure3. Tensile curves of PERT HDPE 2, compared at -20, 23, 60, 100°C.

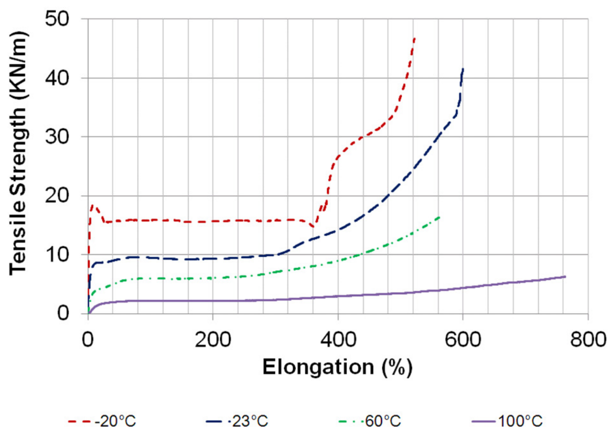

Figure 4. Tensile curves of LLDPE, compared at -20, 23, 60, 100°C.

When evaluated at break, all polyolefins reached an elongation over the climatic chamber allowable travel distance, about 800% elongation. Indeed, polyethylene-based resins will reach over 800%, whereas the other non-reinforced resins reached a maximum of 500 to 600% at 100°C. Table 2 shows the elongation at break of the tested materials.

Table 2. Average elongation at break (%).

Material	Température			
	-20°C	23°C	60°C	100°C
PVC Alloy 1	109	357	509	594
PVC Alloy 2	11.5	13.6	16.9	19.9
PTFE	69	315	437	524
LLDPE	525	608	>800	>800
Polyolefin alloy	575	775	>800	>800
Fortified HDPE	468	832	>800	>800
PERT HDPE 1	683	767	>800	>800
PERT HDPE 2	147	680	>800	>800

The evaluation of the elastic modulus using the highest slope of the initial portion of the tensile curve of the materials is shown on Figure 2, using tensile tests. The graph suggests a greater influence of temperature on non-reinforced materials, however, high density polyethylene maintains a greater elastic modulus at high temperature, particularly PERT HDPE. Under tension below the material yield stress, the elastic modulus represents the ability of the material to support loads under strain. In most configurations where tensile load in hot conditions is suspected, the retention of the elastic modulus will retard eventual elongation of the geomembrane.

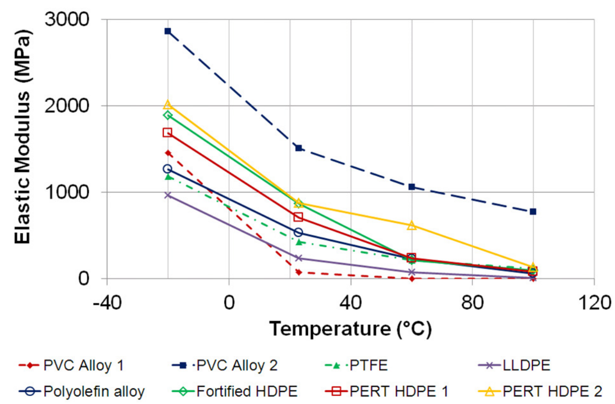

Figure 5. Effect of temperature on the tensile modulus.

In addition, DMA storage modulus was done to modelize the elasticity on continuous heating ramp. DMA Storage Modulus will include the effect of hysteris due to cycling, and causing permanent deformation. Materials with greater ductility, as PTFE and LLDPE, were measured with a lower storage modulus by DMA than elastic modulus by tensile testing.

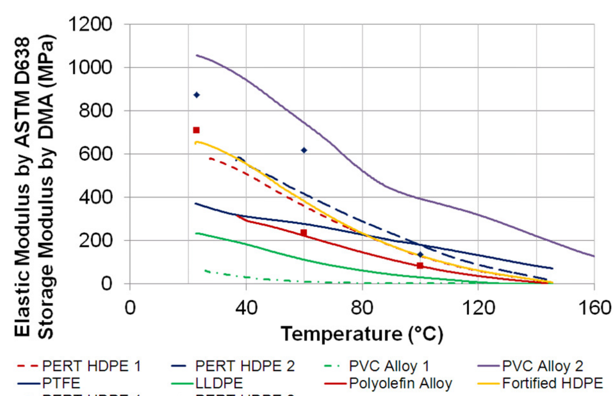

Figure 6. Storage Modulus measured by DMA and compared with tensile elastic modulus.

6 CONCLUSIONS

Eight materials were compared for their ability to resist tensile stress at high temperature. Tensile strength and elastic modulus were measured and compared between materials. PERT high density polyethylene is a promising material having a greater tensile resistance than control HDPE materials, Overall, the comparison between materials has pictured the higher tensile strength of fabric-supported PVC.

Polyethylene-based geomembranes have shown a softening point over 60°C, improvements to formulations are thus desired for optimal field performance. On the other hand, polyethylene's ductility could preserve functionality, passed its yielding point. Further development of tests is planned to assess functionality.

REFERENCES

Mills, A., Martin, D., 2008, Development of high temperature resistant geomembranes for oil sands secondary containments, GeoEdmonton 2008.

ASTM D638-14 Standard Test Method for Tensile Properties of Plastics

ASTM D882-12 Standard Test Method for Tensile Properties of Thin Plastic Sheeting.