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GSI White Paper #28

"Cold Temperature and Free-Thaw Cycling Behavior of Geomembranes and Their Seams"

by

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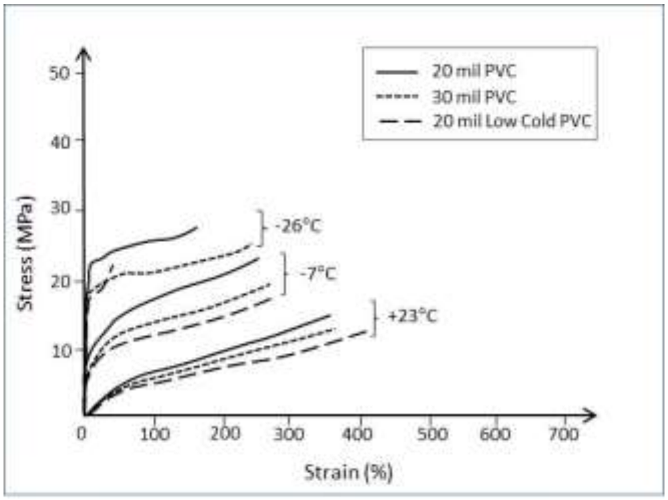
Introduction

It is common knowledge that materials in general, and polymeric materials in particular, will somewhat soften and increase in flexibility under high temperatures and will conversely somewhat harden and decrease in flexibility under cold temperatures. While there are indeed circumstances where high ambient temperatures are important, this white paper focuses entirely on cold ambient temperatures. Even further, it addresses cold temperature behavior of the various geomembranes by themselves and, most importantly, the freeze-thaw cycling behavior of a large number of geomembrane sheets and their seams.

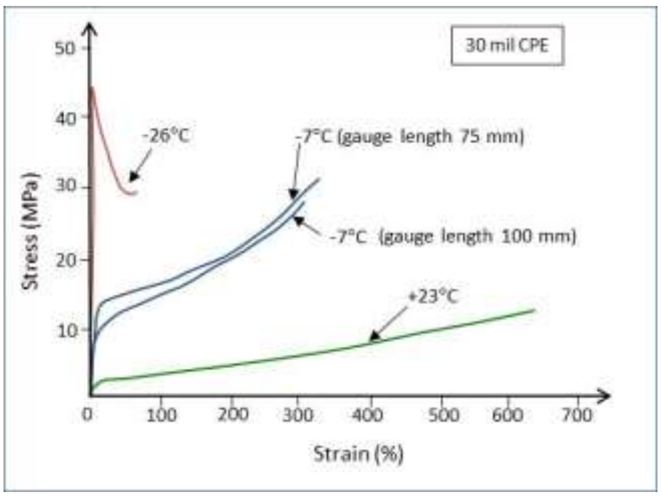
The stimulus for writing the white paper is the myriad questions that regularly come to GSI as to the potential negative effects on the tensile strength of geomembranes and their seams under cold temperature and cyclic freeze-thaw field conditions. As will be seen, the primary source for the information to be presented herein is a joint U.S. EPA/U.S. BuRec study conducted by Alice Comer and Grace Hsuan in 1996. Other companion technical information will also be presented.

Cold Temperature Behavior of Geomembranes

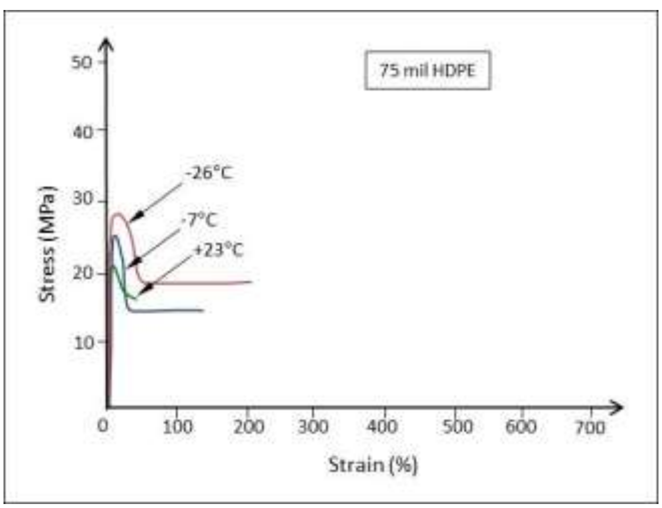
A report by Thornton and Blackall (1976) appears to be the first in describing Canadian experiences with geomembranes in cold regions. Subsequently, Rollin, et al. (1984) conducted a laboratory study on 21 types of geomembranes at temperatures down to - 35°C. They found increasing tensile strength with decreasing temperature. Richards, et al. (1985) did similar studies which also resulted in an increase in strength and a decrease in elongation with decreasing temperatures. They evaluated PVC, CPE and HDPE geomembranes and presented the stress-versus-strain curves at +23°C, -7°C and -26°C temperatures; see Figures 1a, 1b, and



(a) Tensile test results for PVC geomembranes



(b) Tensile test results for CPE geomembranes



(c) Tensile test results for HDPE geomembranes

Figure 1 – Stress-versus-strain behavior of three geomembrane types under progressively colder testing environments, Richards, et al. (1985)

1c. Here one can readily observe how the sets of curves transition from relatively ductile behavior at +23°C, to relatively brittle behavior at -26°C, with the intermediate behavior at -7°C. There are a few outliers, but the trends are undeniable. This general behavior was confirmed by Peggs, et al. (1990) and Giroud, et al. (1993), the latter working with both smooth and textured HDPE geomembranes.

While this type of thermal behavior is of interest, such information for a specific type of geomembrane must be obtained by performing or commissioning individual tests so as to obtain actual design information. Such individual testing is required due to the uniqueness of each polymer type and its specific formulation. Additives such as plasticizers, fillers, antioxidants, carbon black, colorants, etc., can influence the results to varying degrees. Even the resins themselves have behavioral differences at different temperatures. For example, the glass transition temperature of propylene is -7°C, below which the polymer is glassy and above which it is characterized as rubbery. In such a case the tensile properties are greatly influenced, as well as the material's creep and stress relaxation behavior.

There are other aspects of cold temperatures on geomembranes that go beyond the scope of this white paper. In particular are cases of impact shuttering failures in cold climates and installation concerns such as frozen subgrade, bridging, snow and ice removal and worker discomfort, Burns, et al. (1990).

<u>Freeze-Thaw Cycling of Geomembrane Sheets and Seams</u>

Budiman (1994) reported on both cold temperature behavior but also appears to be the first to include freeze-thaw cycling for up to 150 repetitions. He focused entirely on HDPE sheet (of different thicknesses) but not on seams. There was no degradation observed during his tests but he suggested that more cycles would be appropriate. At approximately the same time a much larger freeze-thaw study was ongoing. The final report by Comer and Hsuan was released by the U.S. Bureau of Reclamation in 1996. Related papers leading up to this final report are Hsuan, et al. (1993), Comer, et al. (1995), and Hsuan, et al. (1997). Their combined study involved 19 different geomembrane sheet materials and 31 different seam types. Furthermore, seven different resin types were evaluated. The resin types were the following:

- polyvinyl chloride (PVC)
- linear low density polyethylene (LLDPE)
- high density polyethylene (HDPE)
- flexible polypropylene (fPP)
- chlorosulfonated polyethylene (CSPE)
- fully crosslinked elastomeric alloy (FCEA)

All except FCEA are currently available, however, changes in additives and formulations have occurred and will likely to do so in the future. The entire study was conducted in four discrete parts although the fourth part was focused on induced tensile stress and stress relaxation and is not the specific purpose of this white paper. See Table 1 for the relevant three parts of their study.

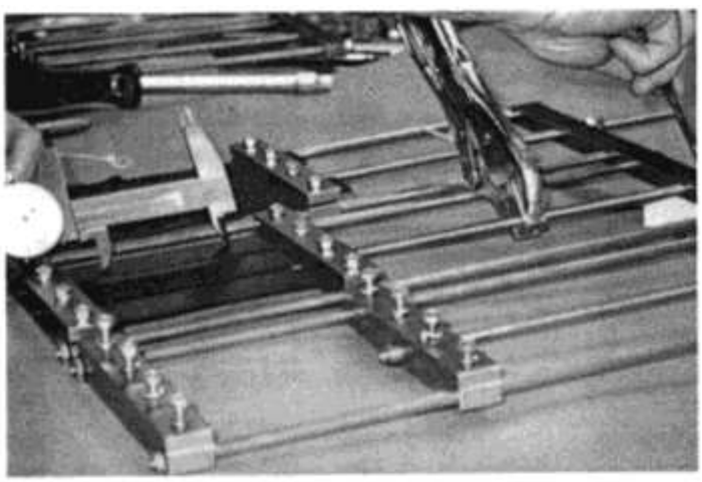
Table 1 – Experimental Design of Different Parts of Comer and Hsuan (1996) Study

Part	Cyclic Temperature Range	Maximum Cycles	Incubation Condition	Tensile Test Temperature
I	+20°C to -20°C	200	relaxed	+20°C
II	+20°C to -20°C	200	relaxed	-20°C
III	+30°C to -20°C	500	constrained	+20°C

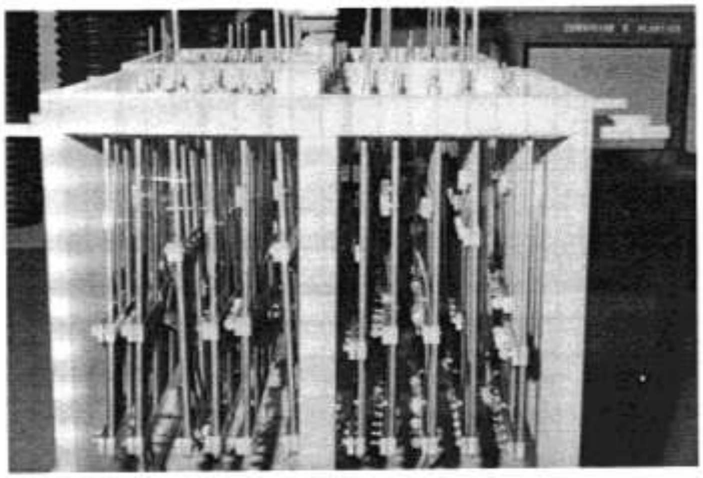
Part I consisted of 19 sheet materials and 27 seams. They underwent freeze-thaw cycles at +20°C for 8 hours and then -20°C for 16 hours. Tensile tests were then conducted at +20°C after 1, 5, 10, 20 50, 100 and 200 cycles.

Part II consisted of 6 sheet materials and 13 seams. They also underwent freeze-thaw cycling at +20°C for 8 hours and then -20°C for 16 hours. Different in this regard was that tensile tests were then conducted at -20°C after 1, 5, 10, 20, 50, 100 and 200 cycles. The -20°C tests were conducted in an environmental chamber (both specimens and their grips) cooled by liquid nitrogen and set at -20°C temperature.

Part III consisted of the same set of 19 sheet materials and 27 seams as in Part I but were now tensioned at a constant strain during the freeze-thaw cycling. The rack used for the tensioning is shown in Figure 2a and the assembly within the environmental chamber is shown in Figure 2b. After the targeted number of freeze-thaw cycles at +20°C for 8 hours and -20°C for 16 hours, specimens were removed and tested at +20°C after 1, 10, 50, 100, 200 and 500 cycles.



(a) Method of applying tensile load to test specimens in Part III tests



(b) Geomembrane racks in holding frame used in Part III series

Figure 2 – Method used for tensioning samples during incubation; Comer and Hsuan (1996)

Rather than showing the graphic results of the above freeze-thaw cycling study (it is available in full in the Comer and Hsuan report by the Bureau of Reclamation and the related papers by these authors) only the concluding comments will be reproduced here. They follow verbatim from the report.

Part I – Results on 200 Freeze-Thaw Cycles Tested at +20°C

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Part II – Results on 200 Freeze-Thaw Cycles Tested at -20°C

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Part III – Results on 500 Freeze-Thaw Cycles Tested at +20°C in a Constrained Condition

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Conclusion and Recommendations

This two-part white paper focused initially on the cold temperature tensile behavior of the stress- versus-strain curves of several different types of geomembranes. As expected, the colder the temperature the more brittle, hence less ductile, were the response curves. Geomembranes made from PVC, CPE and HDPE were illustrated in this regard. The recommendation reached for this part of the white paper is that if a formulation-specific geomembrane under site-specific conditions is to be evaluated for its stress-versus-strain response, actual tests must be commissioned accordingly. The literature can only give general trends in this regard.

The second (and more important) part of this white paper focused entirely on freeze-thaw behavior of geomembranes and their different seam types. The U.S. Bureau of Reclamation report is extremely revealing in this regard. *The conclusion that the authors reached is that there is simply "no change" in tensile behavior of geomembrane sheets or their seams after freeze-thaw cycling.* It is felt that this conclusion in the context of their study is so impressive that it has essentially "closed the door" to further research on this specific topic. The essential question often raised in this regard, i.e., "will freeze-thaw conditions affect geomembrane sheets or their seam behavior," is answered with a resounding "NO".

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