Effects of Temperature on Physical Behaviour of Geomembranes

J. Budiman
Illinois Institute of Technology, Chicago, IL, USA

ABSTRACT: Laboratory experiment was conducted on the high density polyethylene (HDPE) geomembranes. The geomembrane samples were subjected to temperature cycle by storing it in the oven and in the freezer repeatedly. In the process, the edges of the sheet samples were subjected to three different boundary conditions; unrestrained, restrained in one direction, and restrained in both directions. The uniaxial tensile tests were performed at various temperature ranging from 20°C to -20°C. Variables considered were the number temperature cycles, the boundary conditions, thickness of the geomembranes, plain and seamed material, and the temperature. On the effects of temperature cycle, the results show no significant degradation on the stress-strain behavior of the material after being subjected to 150 low-high temperature cycles. On the effects of temperature at testing, the stress-strain diagrams indicate a pattern where decreasing temperature results in an increasing stress level at yield, and decreasing strain at yield, in addition, the ultimate strength is achieved at lower strains level indicating the increase of embrittlement.

1 INTRODUCTION

The use of high density polyethylene (HDPE) geomembranes in liquid storage facilities, reservoir liners, and waste disposal facilities are common. In these facilities, the geomembrane are subjected to daily and annual change of temperature during and after its installation. The continuous temperature fluctuation may influence the performance of the geomembrane in service, especially under extreme temperature variation in winter and summer seasons. Thermoplastic resins like polyethylene was introduced for use as reservoir and landfill liners in the 1960's. Use of geomembranes for liners in landfills and hazardous waste sites increased dramatically in the U.S.A in mid 1980's in response to new U.S. Environmental Protection Agency guidelines. Eigenbrod et al. (1984) presented the most severe incidence of exposure of an HDPE geomembrane to cold temperatures is that of the liner for a brine pond in Fort Saskatchewan, Canada. Koerner (1994) provides a list of geomembrane applications in projects of a geotechnical, environmental, or civil engineering nature.

It has been known that polymer material such as the geomembrane is susceptible to temperature change, it will expand when the temperature increases and will shrink when the temperature decreases. When shrinkage is restricted during temperature decrease, stresses will be induced in the geomembrane. In the field, the movement of the geomembrane due to temperature change is neither perfectly restricted nor completely unrestrained. In the laboratory, the edges of the geomembrane sheet samples were subjected to three different boundary conditions; i.e. restrained in both directions, in one direction and unrestrained. The objective of the research effort was to determine the impact of temperature fluctuations on the physical characteristic of the HDPE geomembrane at room temperature and at very low temperatures.

2 SAMPLE PREPARATION

Large sheets of HDPE geomembrane in three thicknesses of 1.0 mm, 1.5 mm and 2.0 mm was prepared for temperature cycling by cutting a specified number of 35 cm by 35 cm squares to be placed in the restraining frames. Geomembranes in sheet form have a visibly noticeable "grain" or "machine direction" oriented parallel to the direction in which the sheet was travelling when it emerged from the rollers of the manufacturing equipment. In order to investigate any possible anisotropy associated with, samples were restrained in various directions with respect to the machine direction.

In this laboratory study, samples were divided in two groups, the unrestrained and restrained. The unrestrained samples were free to deform during temperature cycle, and hence, no stresses were induced to the material. The restrained samples would be subjected to stress induced by the temperature cycle. Square pieces of HDPE geomembrane were effectively restrained against temperature induced shrinkage by sandwiching the geomembrane between two aluminum frames and then clamping the edges tightly (Budiman and Mills 1992). Different sets of samples were cycled for different numbers of repetitions in order to examine any changes in the material physical properties.

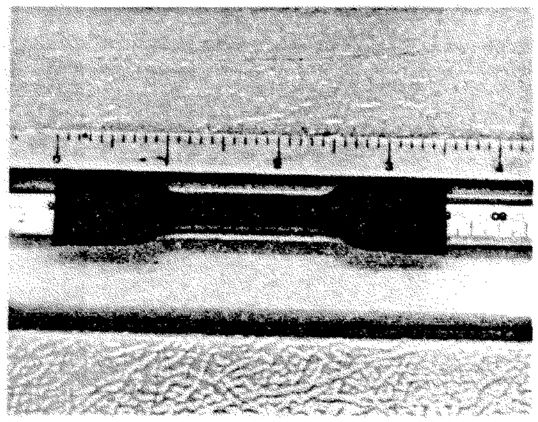

Fig. 1 Geomembrane Test Specimen

Small, narrow, dumbbell shaped samples as shown in Figure 1 were cut for strain-controlled tensile testing from the material which had undergone the temperature cycling regimen. Such testing was chosen because it was determined that the stress-strain diagram resulting from this sort of testing would be a good indicator of any changes in the HDPE which may have been caused by temperature cycling. These tests were conducted at room temperature and at very low temperatures to record the changes in the behavior (embrittlement) of the material due to low temperatures, and to note any differences in the behavior of the temperature cycled material as compared with the behavior of the uncycled samples at similar temperatures.

Initially, samples to be temperature cycled were prepared by mounting them in the restraining frames. The samples were placed in an oven set at 65 degrees centigrade for twelve hours followed by twelve hours in a freezer set at -20 degrees centigrade constituted one complete temperature cycle. The specimens were allowed to cool down or heat up to room temperature for approximately 30 minutes between exposures.

After temperature cycling was completed, the square samples were punched into dumbbell shape to specifications conforming to ASTM D-638 type IV with the dimensions of the narrow portion equal to 0.6 cm by 3.8 cm as seen in Figure 1.

3 TESTING PROCEDURE

A temperature controlled uniaxial testing machine was used for this investigation. The main components of the machine consists of the computerized data acquisition system, a modified large deep freezer box, reaction frame, gearmotor actuator (Mills, 1991). The reaction frame penetrates through the wall of the freezer with its crosshead located inside the box. The bottom end of the reaction frame supports the actuator which is located outside the box. Two extension rods connect the specimen clamp inside the box with the actuator through a loadcell.

In this study, five factors affecting the load-deformation response of the geomembrane were considered, namely: 1) the type of restraint during temperature cycling, 2) the direction of the longitudinal axis of the specimen with respect to the machine direction or "grain", 3) the temperature at which the specimen was to be tested, 4) the number of temperature cycles which the specimen had endured, and 5) the thickness of the specimen.

The four types of restraint during temperature cycling were employed as follows: restrained in the direction parallel to the machine direction, restrained in the direction perpendicular to the machine direction, restrained in both directions, and completely unrestrained. With regard to the second defining aspect, each specimen was either tensile tested parallel to or perpendicular to the machine direction. Concerning testing temperature, the samples were tensile tested at one of the following four different temperatures on the centigrade scale: 20 degrees, zero degrees, -10 degrees, or -20 degrees. Concerning cycle numbers, the samples were made to endure one of the following six numbers of temperature cycle repetitions: zero, one, five, thirty, sixty, or one hundred fifty. Finally, with regard to thickness, the samples were either 1.0 mm, 1.5 mm, or 2.0 mm thick.

Samples tested at temperatures less than room temperature were placed in the testing machine freezer sufficiently long so as to guarantee that the HDPE material itself was at the required temperature at the time of the tensile test. Each specimen was fitted into the jaws of the testing machine clamps and a small seating stress was applied in order to seat the jaws and to straighten out any sag in the samples which were slightly curved. Next, the linear actuator and the data acquisition system were started simultaneously and the "stress" versus strain plot was observed as it traced the sample's behavior on the computer screen. The term "stress" here is defined as the load divided by the initial cross sectional area of the specimen, the area changed significantly with sample elongation. The test was terminated when the sample ruptured.

4 TEST RESULTS

Each sample was tested in tension at the specified temperature, and the load and elongation (or stress and strain) during testing was recorded by the data acquisition system. The tensile tests employed in this study are solely intended to reveal changes in the HDPE behavior due to various factors, and thus it was not intended to determine the strength of the material (ASTM, 1991).

Figure 2 shows the results of a series of tests on 1 mm thick samples which were unrestrained during temperature cycle, oriented parallel to the machine direction. The "stress"-strain responses do not reveal any noticeable variation with respect to the number of temperature cycles that the samples have undergone.

Regarding the effect of repeated temperature fluctuations, this research reveals that in the absence of other deleterious influences, HDPE can be safely said to survive and perform acceptably for a long period of time under conditions involving repetitive temperature fluctuations within the range of -20 degrees to 60 degrees centigrade. Furthermore, there is no evidence to suggest that the material experiences any bond scission, crazing, stress cracking, or thermo-oxidative deterioration as a result of having endured the cycling regimen.

Observing the curves for temperatures at which samples were tested, the HDPE geomembrane material cannot truly be said to be "brittle" at low temperatures in the most rigorous adherence to the classical definition, since even at -20 degrees centigrade the material was still capable of surviving to an elongation at rupture of nearly 500 percent or more. Even so, breakage at 400 percent or 500 percent elongation can be considered brittle behavior in comparison to the breakage at 950 percent elongation exhibited by many of the samples tested at room temperature.

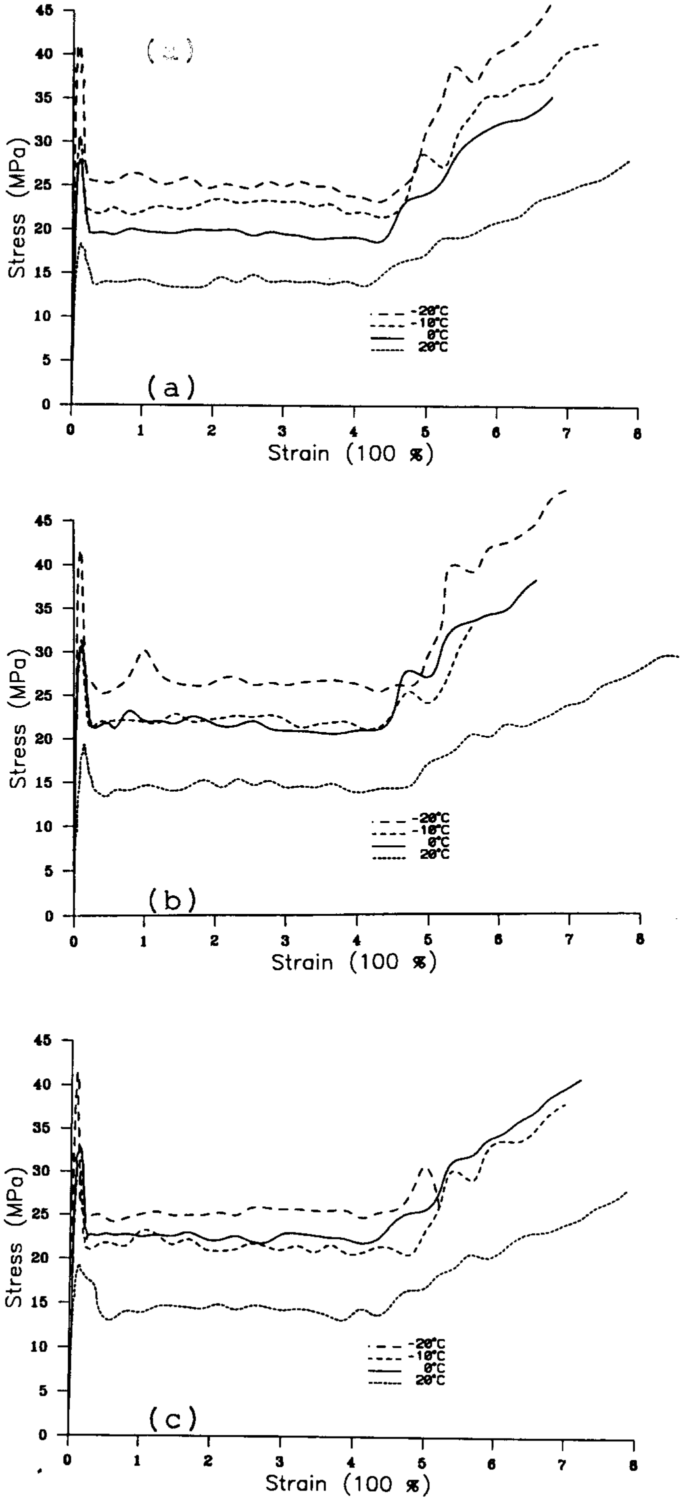

Fig. 2 Stress-Strain Response for Samples Tested at 20 Degrees Celsius (a). 0 Temperature Cycle (b). 1 Cycle (e). 120 Cycles

The preceding stress-strain diagrams indicate a pattern with decreasing temperature of increasing stress at yield, decreasing strain at yield, and decreasing strain at break. In other words, the samples which were tested at low temperatures were stronger but less extensible than the samples which were tested at room temperature. This type of result is precisely what one would expect to see given the fact that previous test results for samples tested at elevated temperatures showed exactly the opposite sort of pattern; that is, with increasing temperature the samples displayed decreasing stress at yield, increasing strain at yield, and increasing strain at break (Mertacon, 1988).

The responses of nearly 600 samples tested are quite similar to those in Figure 3. In addition to the fact that the temperature cycling regimen was found to have no detrimental effect on the tensile load-elongation characteristics of the HDPE geomembrane material in the laboratory, it was also found that the material thickness, the machine direction relative to the direction of tensile testing, and the type of restraint during temperature cycling all have no impact on the characteristics of the stress-strain diagrams of the HDPE material at any of the temperatures investigated. The seamed samples also were not affected by the factors mentioned above except that the elongation at rupture is significantly less than those of plain samples. This is due to the fact that when the seamed samples yielded, only half of the narrow area of the samples undergone deformation, the other half of the narrow area remained undeformed.

The curves for different samples tested at the same temperature were all so similar that one could easily conclude that the only identifying factor which matters in terms of stress-strain behavior of the samples is the temperature at which the tensile tests were conducted.

Interestingly, for the samples tested at low temperatures, the changes in strength properties between the samples tested at zero degrees centigrade and those tested at -10 degrees centigrade were not as pronounced as the changes in strength properties between the samples tested at -10 degrees centigrade and those tested at -20 degrees centigrade.

The stress-strain curves generally begin to change slope and ascend toward rupture stress at approximately 500 percent strain; however, many samples tested at lower temperatures (particularly those tested at -20 degrees centigrade) ruptured in the flat region of the stress-strain curve prior to reaching 500 percent elongation. This phenomena was found to be exhibited in a completely random fashion and was not related to any of the factors in the sample identification code except testing temperature. Some samples tested at room temperature showed this sort of response, but the tendency of a sample to behave in this fashion increased with decreasing temperature. In other words, the inherent variability of the sample's elongation at break was magnified by conducting tests at cold temperatures.

It should be pointed out that the curves for the samples of 1.0 mm thick generally tended to appear slightly more jagged or irregular than either the samples which were 1.5 mm thick or those which were 2.0 mm thick. However, the magnitude of the inherent variability of the HDPE material's strength properties dwarfed this influence on the character of the statistical averages of strength properties.

5 CONCLUSIONS

It can be concluded that the temperature fluctuations up to 120 cycles do not result in any sort of degradation in HDPE geomembranes. Perhaps a much larger number of cycles would yield a more interesting result. The HDPE geomembrane material experiences increasing stiffness with decreasing temperature.

REFERENCES

ASTM (1992) ASTM Standards on Geosynthetics, Philadelphia, Pennsylvania.

Budiman, J. and Mills, W. C. (1992) Effects of Temperature Cycle on Embrittlement of Geomembrane. Proc. Mediterranean Conf. Environmental Geotechnology, Usmen and Acar eds. Balkema, Rotterdam

Eigenbrod, K. D., Irwin, W. W. and Roggensack, W. D. 1984. Proc. Int. Conf. Geomembranes, Denver, Colorado, Volume I. Industrial Fabrics Association International, St. Paul, Minn.

Koerner, R. M. 1994. Designing with geosynthetics. 3rd ed. Prentice-Hall Inc., Englewood Cliffs, N.J.

Mills, W. C. 1991. Embrittlement of high density polyethylene geomembranes at low temperature. MS Thesis, Illinois Institute of Technology.