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Project Summary

Stress Cracking Behavior of HDPE Geomembranes And its Prevention

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The project summarized here focused on the stress cracking behavior and testing of geomembranes made from high-density polyethylene (HDPE). The project included a literature study of stress cracking failures in the field and exhumation of geomembranes at various sites of opportunity. In total, twenty-five cases of stress cracking have been documented since the introduction of this particular material in 1980.

Because of the limitations of the currently used ASTM D 1693 "bent strip" test method for evaluating stress cracking behavior of HDPE geomembranes, a new test was developed—the notched, constant-tensile-load (NCTL) test. Eighteen commercially available sheet materials and seven field-exhumed geomembranes were evaluated using the test. The results led to the recommendation that for an HDPE geomembrane to be acceptably crack resistant, the transition time to the onset of brittle behavior must be greater than 100 hr. The results also indicated that the NCTL test is much more challenging than is the bent strip test.

In addition, two related tests, a single-point, notched, constant-tensile-load (SP-NCTL) test and a seam, constant-tensile-load (SCTL) test was established. The recommendations for both of these tests were that no failure should occur within 200 hr at an applied stress of 30% of yield stress of the sheet for five replicate tests.

The implementation of this set of three tests is oriented toward resin suppliers, manufacturers, designers, and owners involved with HDPE geomembranes. By employing the recommendations made in the full report, the incidence of stress cracking of HDPE geomembranes in the field should be significantly reduced.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, Ohio, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

HDPE is a widely used polymer for manufacturing the geomembranes used in waste containment facilities, partly because the relatively high crystallinity of the material results in excellent chemical resistance. This high crystallinity, however, increases the tendency of the material to stress crack, i.e., the failure of the geomembrane under stress in a brittle manner so that it exhibits little or no elongation adjacent to the failure surfaces.

The initial task of the project was a literature search and subsequent field investigations of stress crack occurrences involving HDPE geomembranes. Subsequent tasks focused on laboratory testing. The limitation of the currently used ASTM D 1693 "bent strip" test method led to the investigation of an alternative test to evaluate stress cracking—the NCTL test. The NCTL test procedure, its reproducibility, and its evaluation of commercial sheets and field-exhumed samples were deter-

mined with the use of commercially available geomembranes and field-exhumed geomembranes that showed varying degrees of stress cracking. The test results led to a quantitative recommendation for acceptance of HDPE geomembranes. In addition, we also compared the NCTL test with the conventionally used bent strip test.

Because of the long testing time required to conduct the NCTL test, a shorter test, the SP-NCTL test, was developed. The SCTL test was also developed to evaluate stress cracking resistance of different types of HDPE geomembrane seams.

Survey on Occurrences of HDPE Stress Cracking in the Field

From both the literature and field investigations it was found:

- stress crack incidents had occurred,
- cracking generally occurred or was initiated at the seams,
- the geomembranes were exposed, i.e., non soil covered, in all cases,
- all parts of the United States (location - hot/cold, humid/arid, etc.) were involved,
- the actual service life varied 1 to 10 yr, and
- a variety of different resins and manufacturers were involved.

NCTL Test Procedure

As developed in this project, NCTL test specimens are dumbbell shaped with dimensions according to ASTM D 1822. A controlled notch is introduced into one side of the surface to produce a "ligament" of 80% of the nominal thickness of the sheet. After fixing the specimens in position in the test device and loading them to various percentages of their yield stress they are immersed in a constant temperature bath maintained at 50°C. The bath is filled with a surface active wetting liquid. Failure occurs as either ductile elongation (at the higher stress levels) or as brittle failure (at the lower stress levels). The failure times of the test specimens are recorded to an accuracy of 0.1 hr.

To obtain the test response resulting from a series of differently stressed test specimens in the NCTL test, the logarithm of percent yield stress is plotted against the logarithm of average failure time for the entire set of test specimens evaluated (see Figure 1). The resulting curve consists of two uniquely linear regions. The linear portion of the curve at high stresses and short failure times is called the "ductile" region." The linear portion at low stresses and long failure times is called the "brittle region." The portion of the curves that separates these two regions is called the "transition region." Four unique characteristics, or parameters, can be obtained from the resulting curve:

- time for onset of the brittle region, defined as the transition time,
- stress at onset of the brittle region, defined as the transition stress,
- slope of the ductile portion of the curve, and
- slope of the brittle portion of the curve.

Of these, the "transition time" was selected as the parameter of primary focus.

Reproducibility of NCTL Test Results

To evaluate the tests reproducibility, three complete sets of NCTL tests were performed on a sample of the same type and lot of a 2-mm (80-mil) HDPE geomembrane. The results indicated that the coefficient of variation of the transition times was within 12%. This was considered acceptable reproducibility at least within a single test laboratory.

The test method has also been evaluated by independent laboratories in connection with ASTM interlaboratory tests to establish precision and bias. Although the tests are not concluded, the results to date are very promising.

NCTL Test Results and Recommendation

The results from the 18 commercial geomembranes indicated a wide variation in their transition time values, ranging from 10 to 5000 hr. In contrast, there was much less variation in the transition stress, the variation ranging from 28% to 40% of yield stress. Thus it was concluded that transition time should be the parameter of choice for comparing and contrasting stress cracking resistance of different HDPE geomembranes. The transition times from the NCTL test of the seven field-exhumed geomembranes ranged from 4 hr to 97 hr. Since the field geomembranes had actually shown various degrees of stress cracking during their service periods, the recommended acceptance criteria must be greater than 97 hr, which was the best of the field samples. The nearest round number that is higher than 97 hr is 100 hr, which was selected as being the minimum recommended acceptable transition time. It should be noted that of the 18 commercial geomembranes, 10 are higher than 100 hr transition time and thus are acceptable under this recommendation.

Comparison between NCTL Test and Bent Strip Test Results

The currently used test method that qualifies the stress cracking resistance of HDPE Membranes is ASTM D 1693, the bent strip test. The results, given as either pass or fail, are based on a criterion defined by the National Sanitation Foundation in NSF #54. Fourteen of the 18 commercial geomembranes were so tested and only one geomembrane failed the criterion. In contrast, 7 out of the same 14 geomembrane samples failed the NCTL test when using the criterion of 100 hr transition time. Of the 7 field-exhumed geomembranes, 4 failed the bent strip test. In contrast, the NCTL test criterion disqualified all 7 of the geomembranes since the acceptance criterion used this set of data as its control group. This indicates that the bent strip test cannot adequately evaluate the stress cracking resistance of HDPE geomembranes.

Single-Point, Notched, Constant-Tensile-Load (SP-NCTL) Test

An SP-NCTL test was developed to decrease the testing time of the complete NCTL test so that the stress cracking resistance of the geomembrane could be confirmed on a pass/fail basis within a relatively short period of time. The concept of the test was to select a single, applied stress level slightly below the initial onset of the brittle region of the geomembrane and then observe whether the failure time of the test specimens exceeded a specified value. The single applied stress level has been set at 30% of the yield stress of the material, and the minimum time recommended for acceptance is 200 hr. Five replicate test specimens should be evaluated, and all should pass the minimum recommended value.

Seam Constant-Tensile-Load (SCTL) Test

An SCTL test was also developed to evaluate the quality of an HDPE geomembrane seam to see whether it has a stress crack resistance comparable to the sheet material. The sheet material and the seam can be directly compared only if their stressed geometries are the same. Hence, seam test specimens notched as described above were used to develop

the SCTL test. Paralleling the single-point test, the selected applied stress was 30% of the yield stress of the sheet material and the minimum failure time recommended for acceptance is 200 hr. Five test specimens should be evaluated, and all should pass the minimum recommended value.

Conclusion

Because of the concern about HDPE geomembranes stress cracking, a suitable laboratory test is essential to evaluate commercially available resins, their formulation, and their manufacture. In this project, the NCTL test was developed and used to evaluate 18 commercially available geomembranes and 7 field-exhumed geomembranes. The results revealed a large variation in the transition time of the onset of brittle failure. An evaluation of the test results led to a recommendation that the transition time for an acceptable HDPE geomembrane should be 100 hr or longer.

The comparison between the NCTL test and the currently used bent strip test indicated that the bent strip test is inadequate to assess the stress cracking resistance of HDPE geomembranes. The NCTL test is much more challenging and authoritative.

Since completing the NCTL test curve in its entirety is time consuming, a single-point test (SP-NCTL) has been developed as a QC/QA test. In this test, five specimens are to be tested under an applied tensile load equal to 30% of the yield stress. None of the test specimens should fail within 200 hr.

To evaluate HDPE geomembrane seams, the SCTL test was developed. The targeted use of the test is evaluating research and development methods for new seams or new seaming devices. Five notched-seam specimens are tested under a tensile load equal to 30% of yield stress of the sheet. As with the single-point test, none of the specimens should fail within 200 hr.

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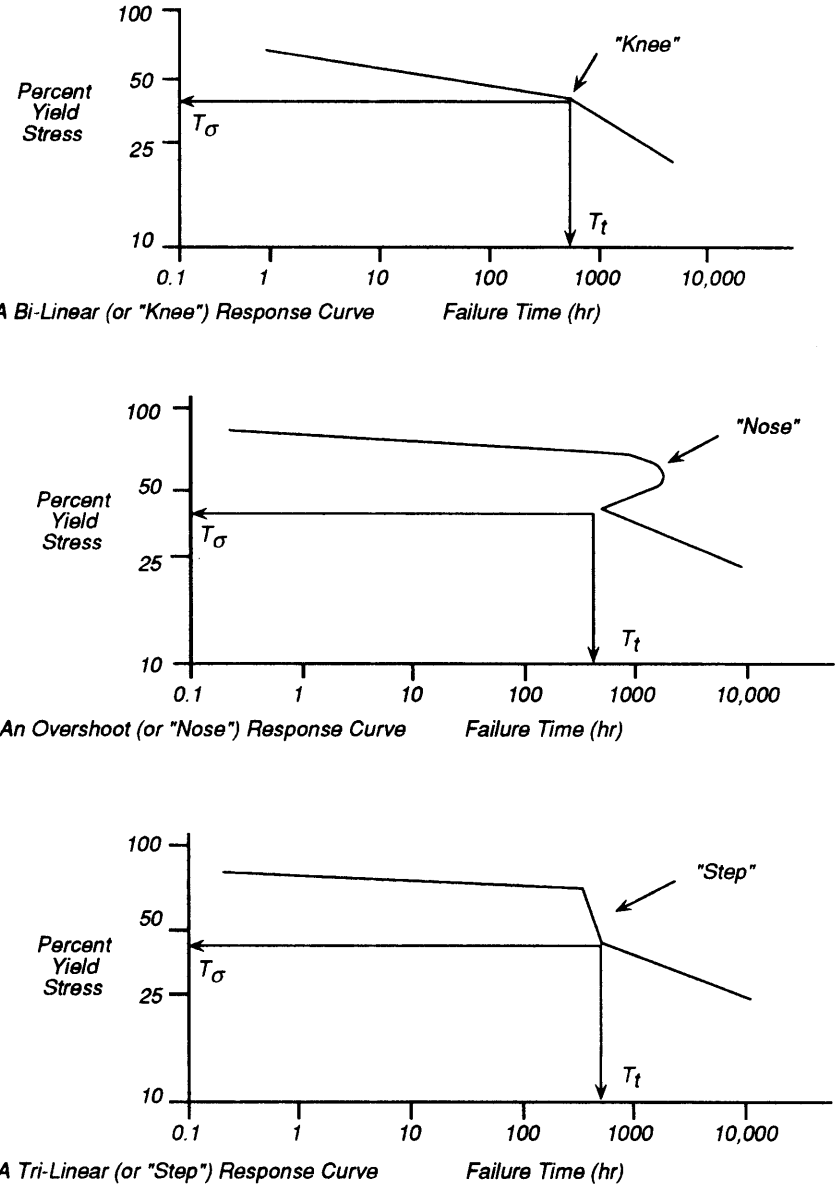

Figure 1. *Typical response curves resulting from a complete notched constant tensile load (NCLT) test.*

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The complete report, entitled "Stress Cracking of High Density Polyethylene Geomembranes and Its Prevention," (Order No. PB93-196616AS; Cost: $27.00, subject to change) will be available only from:
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