# 손상된 지오멤브레인의 응력균열 저항성 해석
# Interpretation of Stress Crack Resistance of Damaged Geomembranes

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**SYNOPSIS :** HDPE smooth and textured GMs were cut into dumbbell shape and notched where depth of the notch produced a ligament thickness of 90% to 10% of the nominal thickness of the specimen at 10% interval. Yield stress and elongation were measured of those samples and plotted on Graph. Yield stress and elongation at yield point decreases gradually as the notch depth is increased. Both installations damaged and notched GMs were used to understand stress crack behavior. Intact sample were notched in such a manner that the depth of notch produced a ligament thickness of 80% of the nominal thickness of the specimen. Installation damaged samples were not notched. Stress Crack Resistance behavior was observed using NCTL Test at 50±1℃ at different yield stresses immerging with pH 4 and pH 12 buffer solutions. Significant difference was observed in both cases.

**Keywords :** geomembranes, laboratory installation damage, loading cycles, stress cracking

## 1. Introduction

Geomembranes have been extensively used in different civil engineering applications in many countries. The main applications include their use as liners for liquid or leachate ponds or as part of composite barrier systems for landfills. In Figure 1, it is seen that geomembrane is used as leachate barrier material.

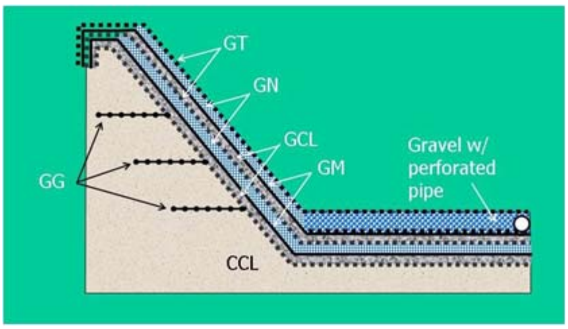



Figure 1. Scheme of waste landfill with geosynthetics

This extensive use is related to their low permeability to water and relative short-term high resistance to a wide range of chemicals. However, it is well known that polymeric materials, like geomembranes, may degrade and their properties may change over time. In the polymer degradation stage of Geomembraneschanges in melt flow index (MFI), stress crack resistance (SCR) and tensile properties are of importance. Among these, stress cracking is likely to have the greatest impact on the actual service life of HDPE GM. Semi-crystalline HDPE GMs are known to be susceptible to stress cracking, which is external or internal cracking in plastic induced by a tensile stress less than its short-term mechanical strength. Stress cracking occurs in a brittle manner with little or no elongation near to the crack surface. One can anticipate that the oxidative degradation of HDPE with time will cause reduction in SCR. The decrease in SCR combined with tensile stresses will lead to cracking in the GM. Thus following extensive cracking GM would no longer act as an effective contaminant barrier. The application of a large external stress or loading on a polymer will result in a decrease in its useful lifetime, primarily via physical creep, although it is possible that chemical degradation mechanisms may also be enhanced. Little has been reported regarding the effect of stress on the degradation of HDPE geomembranes. Stress cracking resistance tests for notched and installed samples were carried out at pH 4 and at pH 12. Tensile behavior at different notch depth was investigated. Crack lengths can be initially quite short but they can grow with time. Eventually the extent of the cracking can lead to excessive leakage in the system, defeating the design function of the geomembrane. That is why both notched and damaged samples were considered. This paper presents findings regarding, changes of mechanical properties on laboratory installation damage, tensile behavior at different notch depth and stress cracking behavior for notched and damaged samples.

## 2. Experimental

### 2.1 Specifications of materials

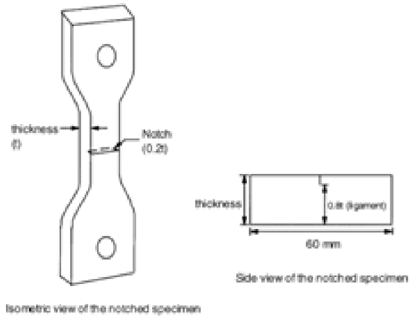
Table 1 shows the specifications of HDPE GMs used in this study.

Table 1. Specification of geomembranes

| Property | Test Method | Surface type of HDPE GMs | |
|---|---|---|---|
| | | Smooth | Textured |
| Thickness [mm] | ASTM D751 | 2.0 | 2.0 |
| Density [g/cm3] | ASTM D1505 | 0.948 | 0.948 |

### 2.2 Notch for Stress Cracking

ASTM D 5397-07(Test method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test) was used as a guide to conduct the stress crack resistance test. HDPE smooth and HDPE textured GMs are cut into dumbbell shape and notched using the notch maker. The depth of the notch produced a ligament thickness of 90% to 10% of the nominal thickness of the specimen at 10% interval. Yield stress and elongation was measured of those samples and plotted on graph. Again, HDPE smooth and HDPE textured GMs were cut into dumbbell shape. Both installations damaged and intact GMs were used to understand stress crack behavior. Intact sample were notched in such a manner that the depth of notch produced a ligament thickness of 80% of the nominal thickness of the specimen. Installation damaged samples were not notched. Figure 2 shows dimension of test specimen, NCTL Test specimen configuration and photo of NCTL test equipment.




(a) (b)

Figure 2. a) NCTL Test specimen configuration b) NCTL test equipment

Stress crack resistance behavior was observed using notched constant tensile load test of virgin notched sample and installation damaged sample at 50±1℃ at different yield stresses immerging pH 4 and pH 12 buffer solutions. pH 4 buffer solution was prepared with acetic acid ($CH_3COOH$) and sodium acetate ($CH_3COONa$). pH 12 buffer solution was prepared with sodium hydroxide (NaOH) and potassium chloride (KCl). Table 2 explains the types of observed sample for stress cracking test at different condition.

pH 4 buffer solution 1 liter = 847㎖ 0.1M acetic acid + 153㎖ 0.1M sodium acetate
pH 12 buffer solution 1 liter = 50㎖ 0.2M KCl + 12㎖ 0.2M NaOH

Table 2. Type of observed sample

| Types of GMs | Condition of GMs | pH of Solution | |
|---|---|---|---|
| | | pH 4 buffer solution | pH 12 buffer solution |
| HDPE smooth | Intact with notch | At 25%, 30%, 35%, 40% yield stress | At 25%, 30%, 35%, 40% yield stress |
| HDPE textured | Intact with notch | At 25%, 30%, 35%, 40% yield stress | At 25%, 30%, 35%, 40% yield stress |

## 3. Results and Discussion

### 3.1 Yield Stress and Yield Elongation at different notch depth

Due to notch geomembranes lose strength like other materials. Yield stress and elongation at yield point decreases gradually as the notch depth is increased. Figure 3 states thenotch percentage at 10% interval across the thickness of geomembranes and their yield stress and elongation at yield point. It explains the traditional experience that yield stress depends on the thickness of materials if the width is constant. It doesn't show any exception along the figure. It can be concluded that yield stress is proportional to the thickness of material at constant width without any significant difference. Rate of decrease in yield stress is almost constant after 20% depth of notch.

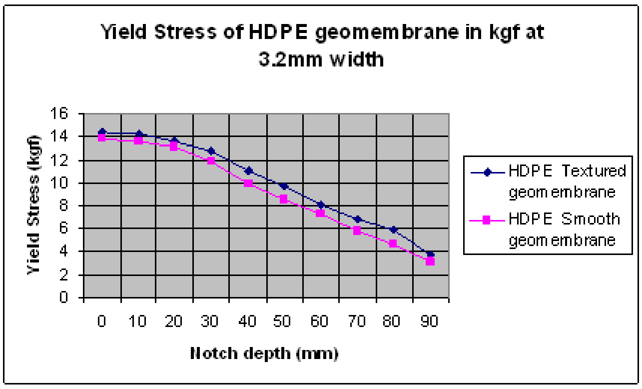



Figure 3. Yield strength of HDPE geomembranes at different notch depth

Figure 4shows the elongation at yield point of different thickness of geomembranes at constant width. In here, elongation at yield point of geomembranes is proportional to their thickness without significant fluctuations at constant width.

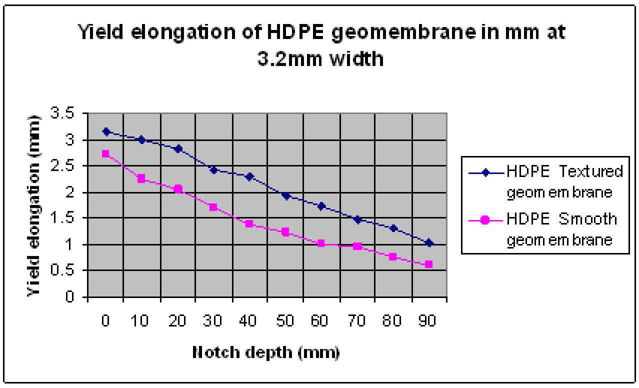



Figure 4. Yield elongation of HDPE geomembranes at different notch depth

Strength Reduction depending on notch depth is shown in Figure 5 that shows the same trend at every point.

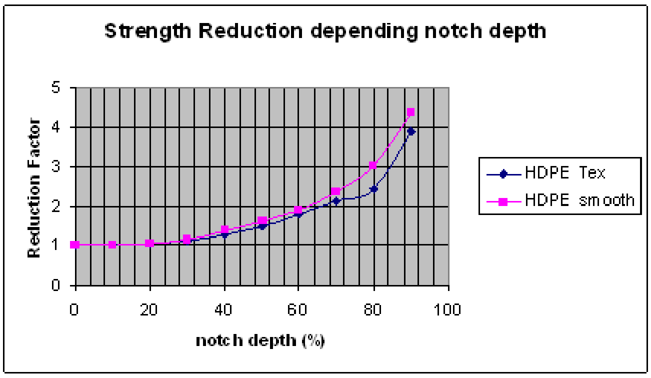



Figure 5. Strength reduction factor of HDPE geomembranes at different notch depth

### 3.2 Stress Cracking Resistance

Stress Cracking of HDPE smooth and textured geomembranes were measured at pH 4 and pH 12 where ASTM D 5397-07 was used as a guide. Notched geomembrane means intact samples with 20% notch of its thickness and damaged sample means laboratory installation damaged sample after 800 loading cycle without any further notch. In this stress cracking resistance test, some samples failed and some of them didn't fail even after one thousand hours. Table 3~10 state the condition of geomembranes at 25%, 30%, 35% and 40% tensile load whether failed or not. These tables also state residual strength. From the data, it seems that residual strength decreases as applied load increases. After data analysis, it seems that at 25% and 30% tensile load geomembranes can withstand more than one thousand hours whereas over 35% tensile load geomembranes become vulnerable to stress cracking where both damaged and notched geomembranes follow the same trend. It is also observed that notched geomembranes possess less strength than installation damaged geomembranes at every stage. It clarifies that 20% notch is an overestimate to understand stress cracking resistance due to installation damage of geomembranes that further intensive investigation considering all relevant factors. Figure 6~9 show the residual strength after stress cracking observation. Some symbols should be interpreted as NF = Not failed after one thousand hours, F(t) = Failed (at time in hour) and B(t) = Broken (at time in hour).

Table 3. Stress cracking observation of HDPE smooth (damaged) geomembranes at pH 4

| Load (%) | Time (hr) | Remark | Strength (kg) |
|---|---|---|---|
| 25 | 1197 | Not Failed | 15.1 |
| 30 | 1197 | Not Failed | 14.9 |
| 35 | 1197 | Not Failed | 14.4 |
| 40 | 246.8 | Failed | 13.2 |

Table 4. Stress cracking observation of HDPE smooth (notched) geomembranes at pH 4

| Load (%) | Time (hr) | Remark | Strength (kg) |
|---|---|---|---|
| 25 | 1104.1 | Not Failed | 13.3 |
| 30 | 1104.1 | Not Failed | 13.1 |
| 35 | 30.6 | Failed | 13 |
| 40 | 0.3 | Failed | 10.9 |

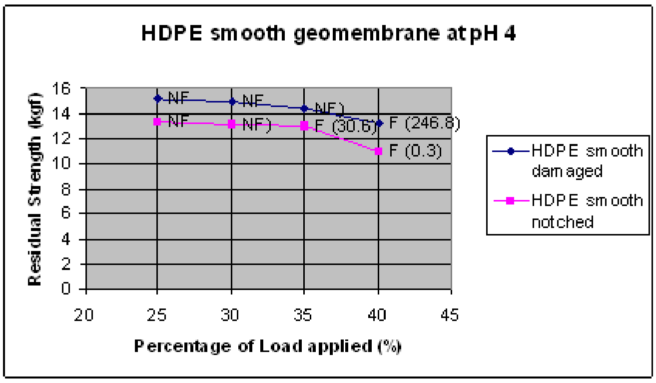



Figure 6. Residual strength of HDPE smooth geomembranes (notched and damaged) after stress cracking observation at pH 4

Table 5. Stress cracking observation of HDPE smooth (damaged) geomembranes at pH 12

| Load (%) | Time (hr) | Remark | Strength (kg) |
|---|---|---|---|
| 25 | 1006.2 | Not Failed | 15 |
| 30 | 1006.2 | Not Failed | 14.4 |
| 35 | 1006.1 | Not Failed | 13.6 |
| 40 | 7 | Failed | 12.5 |

Table 6. Stress cracking observation of HDPE smooth (notched) geomembranes at pH 12

| Load (%) | Time (hr) | Remark | Strength (kg) |
|---|---|---|---|
| 25 | 1003.2 | Not Failed | 13.3 |
| 30 | 1003.5 | Not Failed | 13.1 |
| 35 | 1003.6 | Not Failed | 12.8 |
| 40 | 0.3 | Failed | 11 |

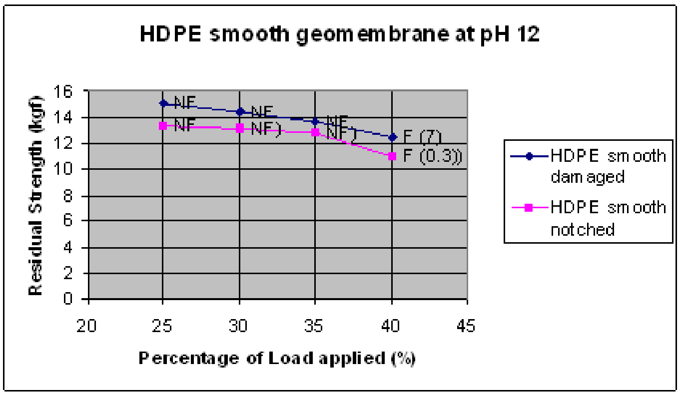



Figure 7. Residual strength of HDPE smooth geomembranes (notched and damaged) after stress cracking observation at pH 12

Table 7. Stress cracking observation of HDPE textured (damaged) geomembranes at pH 4

| Load (%) | Time (hr) | Remark | Strength (kg) |
|---|---|---|---|
| 25 | 1055.3 | Not Failed | 15.8 |
| 30 | 1055.3 | Not Failed | 14.8 |
| 35 | 258.2 | Failed | 13.2 |
| 40 | 1.2 | Failed | 11.7 |

Table 8. Stress cracking observation of HDPE textured (notched) geomembranes at pH 4

| Load (%) | Time (hr) | Remark | Strength (kg) |
|---|---|---|---|
| 25 | 1432.3 | Not Failed | 14 |
| 30 | 554.1 | Failed | 13 |
| 35 | 5.8 | Failed | 0 |
| 40 | 0.2 | Failed | 0 |

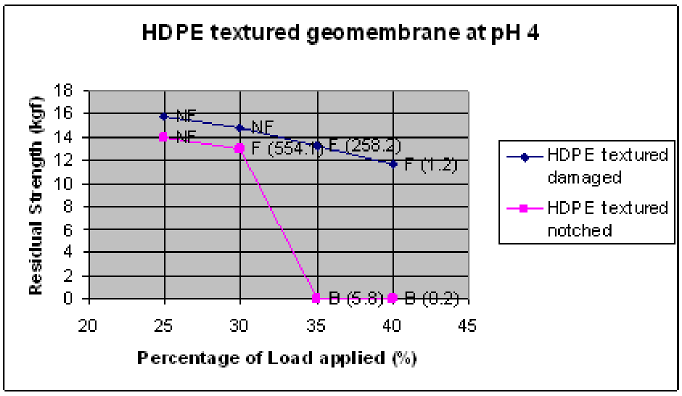



Figure 8. Residual strength of HDPE textured geomembranes (notched and damaged) after stress cracking observation at pH 4

Table 9. Stress cracking observation of HDPE textured (damaged) geomembranes at pH 12

| Load (%) | Time (hr) | Remark | Strength (kgf) |
|---|---|---|---|
| 25 | 1013.6 | Not Failed | 14.7 |
| 30 | 1013.6 | Not Failed | 13.8 |
| 35 | 431.1 | Failed | 13.5 |
| 40 | 1.5 | Failed | 0 |

Table 10. Stress cracking observation of HDPE textured (notched) geomembranes at pH 12

| Load (%) | Time (hr) | Remark | Strength (kgf) |
|---|---|---|---|
| 25 | 1013.6 | Not Failed | 13.4 |
| 30 | 1013.6 | Not Failed | 12.9 |
| 35 | 2.5 | Failed | 0 |
| 40 | 0.2 | Failed | 0 |

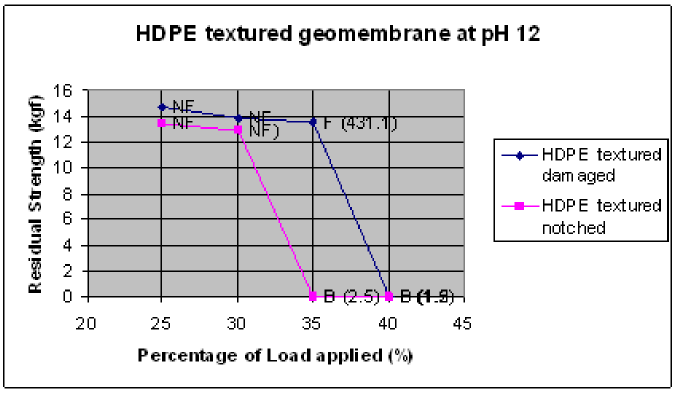



Figure 9. Residual strength of HDPE textured geomembranes (notched and damaged) after stress cracking observation at pH 12

## 4. Conclusion

After the study of tensile strength at different depth of notch, it can be concluded that yield stress is proportional to the thickness of material at constant width without any significant difference. In the stress cracking observation, it is understood that residual strength decreases as applied load increases. After data analysis, it seems that at 25% and 30%tensile load geomembranes can withstand more than one thousand hours without any significant damage whereas over 35% tensile load geomembranes become vulnerable to stress cracking where both damaged and notched geomembranes follow the same trend. It is also observed that notched geomembranes possess less strength than installation damaged geomembranes at every stage. It clarifies that 20% notch is an overestimate to understand stress cracking resistance due to installation damage of geomembranes that further intensive investigation considering all relevant factors. In general, the results show that the tested geomembranes presented some variations in properties after installation damage. Some variations were inexpressive and did not allow establishing a behavior trend of the material which implies that either executed laboratory installation damage is unsuitable to investigate strength reduction with the geomembranes due to installation or error occurred during testing period. More intensive research is needed to find out acceptable correlation between changes in mechanical properties and laboratory installation damage along with the field installation. 20% notch is an overestimate to understand stress cracking resistance due to installation damage of geomembranes that further intensive investigation considering all relevant factors.

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