# Durability analysis of damaged geomembranes under environmental condition

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ABSTRACT: Geosynthetics are exposed to highest mechanical stress during installation. A series of laboratory simulation test for installation damage of geomembrane (GM) was carried out at different loading cycles on HDPE GMs where ISO 10722:2007 was used as a guide. The result of the test is reported and it has been found that number of loading cycle has irregular influence on installation damage. It is known that the service life of a GM depends on the exposure conditions, which in a landfill may involve adverse chemical exposure, elevated operating temperatures, and potentially large physical stresses. New equipment was developed and the installation damaged GM samples were exposed to pH solutions under different stress at elevated temperature for hours. Tensile tests was performed to get the residual strength and analyzed. It has been noticed that as the applied stress on GM samples increases, residual tensile strength decreases and they showed higher tolerance to acidic condition than alkali condition.

*Keywords: laboratory simulation test, installation damage, HDPE GMs, ISO 10722:2007, chemical exposure, residual strength*

## 1 INTRODUCTION

The ideal way of assessing the service life of GM would be by examining actual field samples over the service life. However this is not feasible because it would take too long to obtain results under field conditions. Thus the service life is generally assessed using laboratory-accelerated ageing tests. Therefore, it is necessary to simulate field condition in the laboratory test as best as possible. Otherwise, laboratory test result would have no use to determine service life of the material. The service life of a GM depends on the exposure conditions, which in a landfill may involve adverse chemical exposure, elevated operating temperatures, and potentially large physical stresses. The key parameters to be considered in geosynthetics applications with regard to long-term degradation include temperature, moisture, UV radiation, thermal stress, chemical environment, mechanical stress, microbiological activity and atmospheric pollution. These parameters may – or may not, depending on the type of polymer and presence of synergetic effects – have influence the polymer structure, and eventually the functionality of the product given occurrence of additional synergetic effects. In this paper, at first newly designed equipment is described and then experiments and results are discussed to maintain the flow of presentation. In the experimental, HDPE GM were exposed to pH solution under stress at elevated temperature for hours after laboratory installation damage and residual strength was measured, same specimen were also used for stress cracking resistance observation at pH solution and also tensile strength of notched of different depth specimens were tested to see effects of notch on strength of HDPE GM.

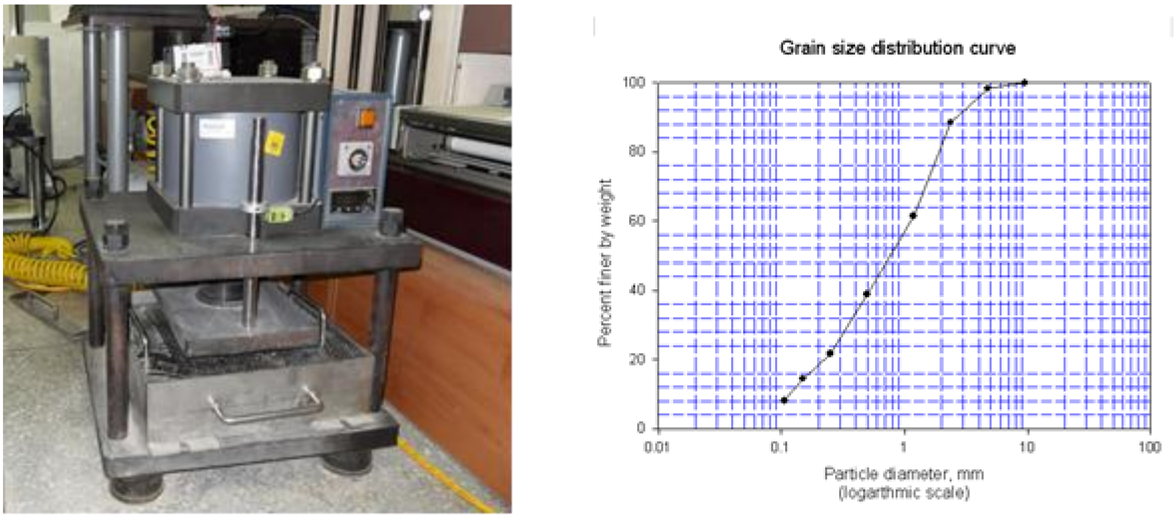
## 2 DESIGN OF TEST EQUIPMENT

Test equipment is designed in such a manner that three parameters can be changed or controlled separately. They are stress, temperature and chemical solution where they effect on the geosynthetics simultaneously. The equipment has three modules. 1) Main frame and loading system 2) Bath 3) Control unit.

Figure 1 shows the photograph of the entire equipment mentioning the units using arrows. The entire equipment has to be made of stainless steel and especial care should be taken on hanging frame that holds the specimen and immersed into chemical solution, and the bath that is full of the chemical solution during the experiments to avoid degradation by rust and corrosion. In the laboratory, there is no useful equipment that stress, temperature and chemical exposure can work on geosynthetics together at a time. Although a geosynthetic liner longevity simulator (GLLS) has been developed to simulate the chemical, temperature, and physical exposure conditions that are expected for a MSW landfill basal liner system in the field, that is expensive and complicated. This newly designed equipment, described above, is cheaper to make and easy to control. It can be very useful tools to conduct experiments with geosynthetics to provide an estimate of the service life. Here should be noted that no laboratory simulation can perfectly substitutes actual field environment. All the simulation may give an idea before mass application in the field. HDPE GM was exposed to pH solution using this equipment which is discussed later in this paper.

## 3 EXPERIMENTAL

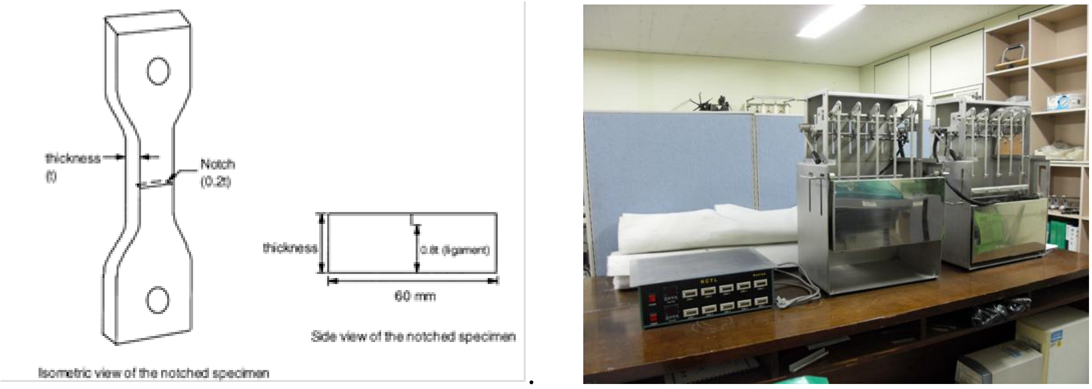
Commercially available HDPE geomembranes of two kinds were tested: smooth (2.0 mm) and textured (2.0 mm). A hydraulic cyclic loading system with a maximum capacity of 80kN and a maximum loading rate of 2.5 Hz was used in the present study. ISO 10722:2007 was used as a guide. Figure 1 (a) shows the photograph of the equipment used for laboratory installation damage. Figure 1 (b) explains the soil particle distribution curve of soil used as fill material for installation damage of GM. The yield strength (ASTM D6693) of HDPE GM (Smooth and textured) at both direction (MD and CMD) due to laboratory installation damage at different loading cycle (intact, 200, 400, 600, 800) is presented.



(a) (b)

Figure 1. (a) Laboratory installation damage test equipment (b) Grain size distribution.

As the installation damaged GM sample with 800 loading cycle is expected to have highest damage (yield strength 30kgf, thickness 2mm), that was used for pH solution exposure. It was exposed to pH 4 and pH 12 buffer solution under their different yield stress at 50°C for hours using the newly designed equipment described earlier section. Table 1 shows exposure parameters. pH 4 buffer solution was prepared with Acetic Acid ($CH_3$-COOH) and Sodium Acetate (CH3-COONa). pH 12 buffer solution was prepared with Sodium Hydroxide (NaOH) and Potassium $_{\text{Chloride}}$ (KCl). Tensile tests was performed in accordance with ASTM D6693 (ASTM 2008C) (Type IV) using dumbbell-shaped specimens in a tensile testing machine at a strain rate of 50 mm/min. Three replicate samples were tested and the average is reported. ASTM D 5397-07(Test method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load (NCTL) 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. 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 dumbbell shape specimen with notch and . Stress Crack Resistance behavior was observed using Notched Constant Tensile Load Test of virgin notched sample and installation damaged sample at 50°±1 C at different yield stresses immerging pH 4 and pH 12 buffer solutions.

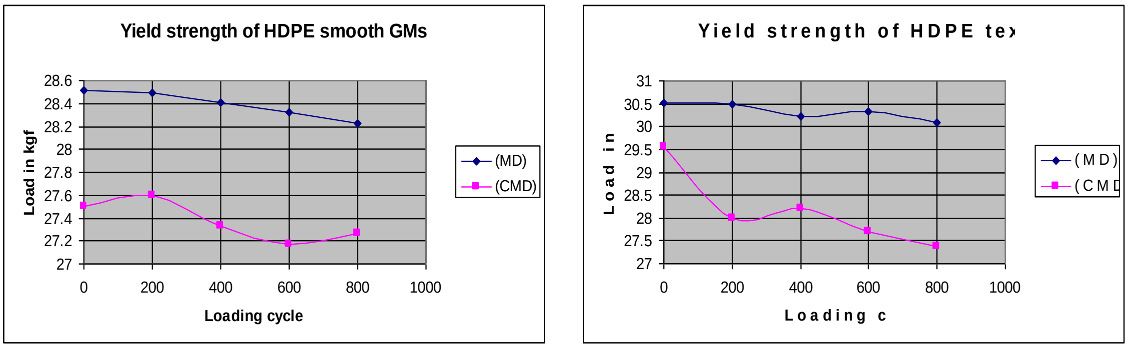


(a) (b)

Figure 2. (a) Notch for test specimen (b) NCTL test equipment.

## 4 RESULTS AND DISCUSSION

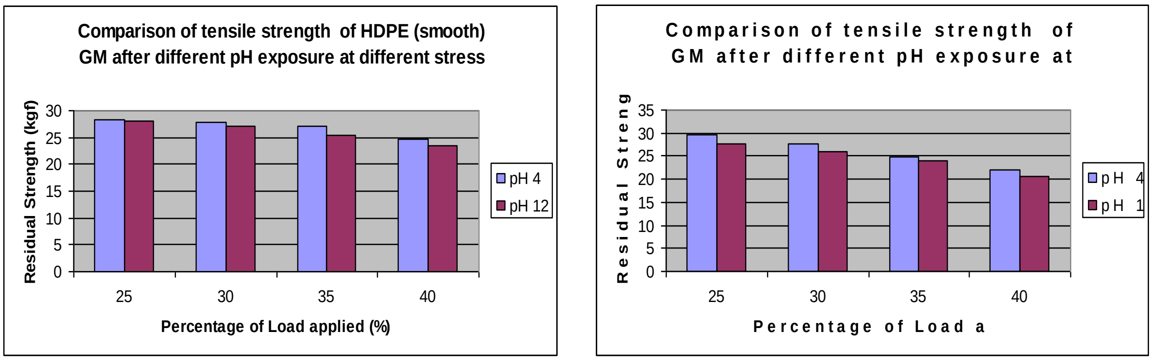
In Figure 3, both smooth and textured HDPE GMs showed gradual decrease in yield strength with the increase in loading cycle with some fluctuations towards cross machine direction. It seems that the decrease is not so significant as even after 800 loading cycle decrease in yield strength is less than 2% for both samples except textured samples in CMD (7.4%) In general, it seems that increase in loading cycle caused more damage on the GM samples. However, any significant changes are not observed that any specific correlation can be drawn. So, we can just say the higher the number of loading cycle, higher the damage that causes declination in yield point. More intensive experiments are needed to obtain better knowledge on installation damage on GMs considering not only particle size and number of loading cycle but also shape or angularity of the particles.



(a) (b)

Figure 3. Yield strength of (a) HDPE smooth GM (b) HDPE textured GM at different loading cycle towards MD and CMD.

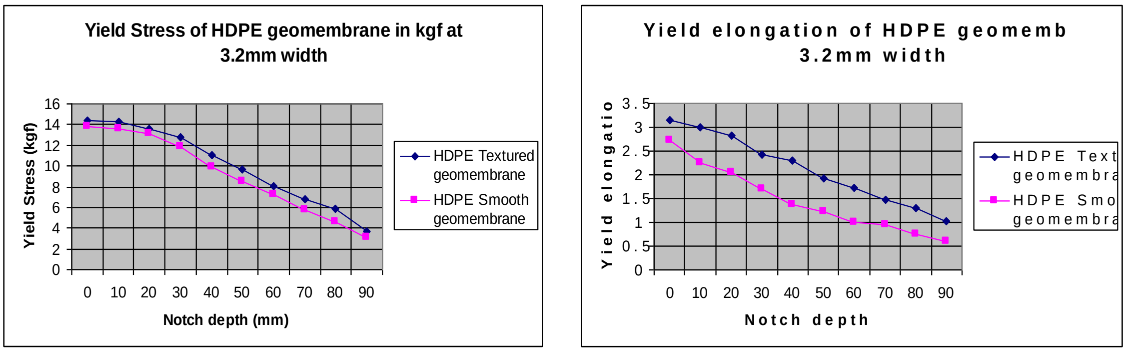
Residual strength of samples after pH solution exposure was compared in the Figure 4. It would help to get an idea of tensile strength in the real field for long time use where three parameters work simultaneously. In this experiment, stress was variable. It has been noticed that as the applied stress increases, residual tensile strength decreases. It can be said that residual tensile strength is inversely proportional to exposed stress. As the temperature was constant, it is difficult to explain the effect of temperature clearly. But it is obvious that a GM will degrade faster at higher temperatures than lower temperatures. However, although it is hard to say confidently, it seems that HDPE GM (both smooth and textured) shows better performance to acidic condition that alkali condition. In our experiment, residual strength was only tested after a fixed period of time. That’s why changes over exposed period were not obtained.



(a) (b)

Figure 4. Comparison of residual strength of (a) HDPE (smooth) GM (b) HDPE (textured) GM after exposure.

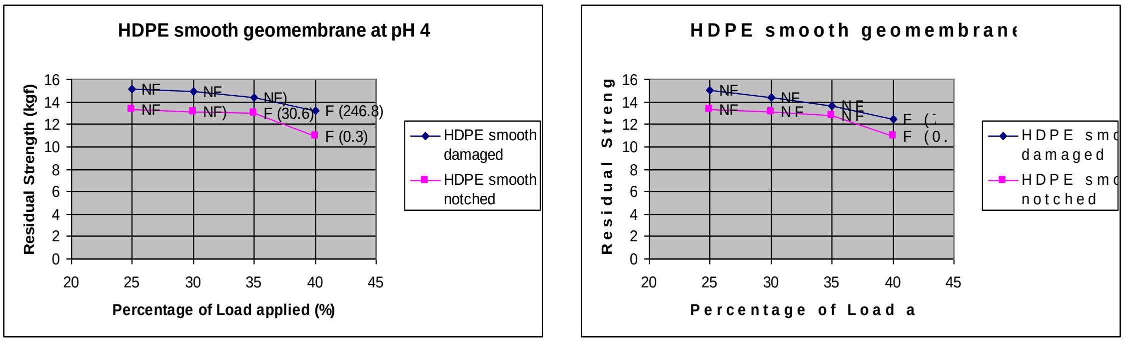
GMs are polymeric material. Therefore, what no significant change in tensile properties doesn't imply no degradation in the material. It is rather more important to know the polymeric degradation and anti-oxidant depletion of GM for the understanding of the service life of GM. Usually, service life of HDPE GM can be divided into three stages where Stage I represents the time for antioxidant depletion, Stage II refers to induction time to the onset of polymer degradation, and Stage III is the polymer degradation involving the decrease in a GM property to an arbitrary level often taken to be 50% of the original value or ‘‘half-life’’. Hence, the service life of a GM is the sum of the three stages. A small amount of antioxidant (typically 0.5-1%) is added to the GM to retard oxidation and increase their service life. The long-term performance of GM in landfill is initially controlled by the rate of antioxidant depletion in Stage I. Oxidation of polymer takes place without any measurable decline in mechanical properties in Stage II. In Stage III oxidative degradation of polymer continues and the mechanical properties (e.g. tensile strength at break) change to the end of service life. From the result of the conducted experiment, it can be easily infer that the GM specimen was still in Stage I. Due to notch GM lose strength like other materials. Yield stress and elongation at yield point decreases gradually as the notch depth is increased. Figure 5 (a) states the notch percentage at 10% interval across the thickness of GM and their yield stresses. 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 5 (b) shows the elongation at yield point of different thickness of GM at constant width. Here, elongation at yield point of GM is proportional to their thickness without significant fluctuations at constant width.



(a) (b)

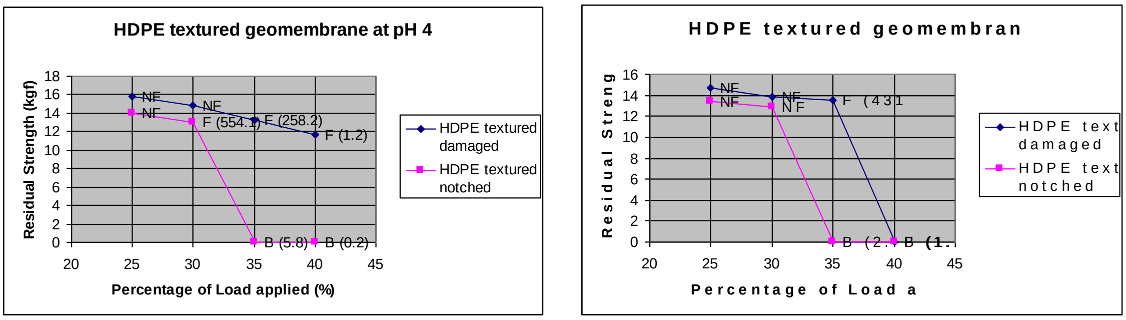
Figure 5. Yield strength and elongation of HDPE GM at different notch depth

Stress cracking property of HDPE smooth and textured GMs were measured at pH 4 and pH 12 where ASTM D 5397-07 was used as a guide. Figure 6 and 7 shows 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).Notched GM 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 test, some samples failed and some of them didn't fail even after one thousand hours. It seems that residual strength decreases as applied load increases. After data analysis, it seems that at 25% and 30% tensile load GM can withstand more than one thousand hours whereas over 35% tensile load GM become vulnerable to stress cracking where both damaged and notched GM follow the same trend. It is also observed that notched GM possesses less strength than installation damaged GM at every stage. It clarifies that 20% notch is an overestimate to understand stress cracking resistance due to installation damage of GM that further intensive investigation considering all relevant factors.



(a) (b)

Figure 6. Residual strength (a) pH 4 and (b) pH 12 of HDPE smooth GM (notched and damaged) after stress cracking



(a) (b)

Figure 6. Residual strength (a) pH 4 and (b) pH 12 of HDPE textured GM (notched and damaged) after stress cracking

## 5 CONCLUSION

It can be concluded that higher the number of loading cycle, higher the damage that causes declination in yield point. More intensive experiments should be conducted to obtain improved knowledge on installation damage on GMs considering not only particle size and number of loading cycle but also shape or angularity of the particles. Newly developed experimental equipment that is capable of simulating the ageing of geosynthetics under the combined effects of chemical exposure, elevated temperatures and applied stresses is described. It has been seen that HDPE GM is more resistant to acidic condition than alkali condition. Residual tensile strength is inversely proportional to exposed stress. Also 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 GM can withstand more than one thousand hours without any significant damage whereas over 35% tensile load GM become vulnerable to stress cracking where both damaged and notched GM follow the same trend. It is also observed that notched GM possesses less strength than installation damaged GM at every stage. It clarifies that 20% notch is an overestimate to understand stress cracking resistance due to installation damage of GM that requires further intensive investigation considering all relevant factors.

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