Compatibility of Containment Systems with Mine Waste Liquids

Project I.D.: R/UW-CTP-001S

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Period of Contract: July 1999 - June 2001

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1. PROJECT SUMMARY

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Background/Need:

Great interest has arisen in metallic mining at various locations in Wisconsin. Significant concern has developed regarding the potential for environmental impacts of mining, particularly the pollution of groundwater. This concern has arisen due to the poor environmental track record of most mining companies.

Mining's greatest threat to groundwater is pollution from drainage of mine tailings. Tailings are the residue remaining after benefication of the ore. Drainage from tailings may consist of process water present at the time of disposal or acidic water caused by percolate passing through tailings undergoing oxidation. Acidic mine drainage pollution is characterized by a low pH and elevated concentrations of heavy metals affecting both surface and groundwaters.

One method to prevent groundwater contamination is to place tailings in an engineered waste containment facility designed using the principles employed for modern municipal and industrial landfills. Design of an engineered containment system consists of reducing the leakage to a negligible amount so that the only important contaminant transport mechanism is molecular diffusion. Recent studies sponsored by USEPA have shown that modern landfill liners do perform as intended and have very low leakage rates typically less than 30 L/ha-d (1 mm/yr). However, mine tailings are very different than municipal waste and stabilized hazardous waste placed in industrial landfills. Thus the lining systems used for municipal and industrial waste may perform differently when they are exposed to mine drainage. In fact, an extensive review of literature has revealed no case studies regarding the environmental performance of engineered containment facilities for tailings. Therefore, efficiency of the lining systems used for mine waste containment must be assessed in order to make responsible decisions regarding mine waste management.

Objectives:

The main objective of this study is to assess the compatibility of lining system materials and mine waste liquids, with the intent of determining if materials used for lining systems will function as intended when they are exposed to mine waste liquids. The second objective is to predict the lifetime of lining system materials by extrapolating the experimental behavior to site-specific conditions.

Methods:

A variety of lining system materials (geomembrane, geotextile, and geocomposite) are exposed to synthetic acidic mine drainage solution and two control solutions. A modified version of EPA Method 9090 is used for exposure.

Geosynthetic materials are immersed in the chemical environment for a period of 15 months at 20 ^{o}C, 40 ^{o}C and 60 ^{o}C. Three different chemical environments are used for the exposures: Control I (Deionized water), Control II (low pH, no metals solution), and synthetic acidic mine drainage (low pH, high metals solution).

During exposure, samples are periodically taken from the immersion tanks, and physical and engineering properties of geosynthetics are tested to confirm whether the liquids have an adverse effect on engineering properties. The following tests are performed on unexposed and exposed samples: thickness, mass, tear resistance, puncture resistance, tensile strength, elongation at break, modulus of elasticity, melt flow index test, transmissivity test and infrared spectroscopy analysis, which is a special tests used for the detection of degradation in polymer science.

Results and Discussion:

Comparison of exposed and unexposed geomembrane samples of acidic mine drainage set over a period of 6 months suggests that the HDPE geomembrane was slightly deteriorating due to exposure. This deterioration was not easily detectable with puncture and tear test results due to the high standard deviations recorded in these tests. Puncture and tear strength values recorded during the exposure were fluctuating within the high standard deviations of unexposed samples. Melt flow index (MFI) results also suggest a certain amount of degradation of the geomembrane. Test results have still fluctuations mostly within the standard deviation of unexposed samples for geotextiles. This made it difficult to detect any degradation over this short period of exposure. Significant reduction in transmissivity values were observed in geotextile in acidic mine drainage exposure at 60 ^{o}C.

Conclusions/Implications/Recommendations:

Even though exposure and experiments are continuing, following conclusions can be drawn for the first six months of the study: HDPE geomembrane has slightly deteriorated due to acidic mine drainage exposure as it was concluded from wide width test and melt flow index results. This deterioration was not easily detectable with puncture and tear test results due to the high standard deviations recorded in these tests; for geotextile specimens, significant changes physical and engineering properties were not detected due to high variability in the test results of unexposed samples. However, reductions in the transmissivity results were detected for geocomposite (i.e., geonet) specimen.

These results and conclusions will be updated with continuing testing.

Kew Words:
acid mine drainage, groundwater, landfill liners, mining, tailings, chemical compatibility, geosynthetics

Funding: UWS Groundwater Research Program

2. INTRODUCTION

Great interest has arisen in metallic mining at various locations in Wisconsin. Significant concern has developed regarding the potential for environmental impacts of mining, particularly the pollution of groundwater. This concern has arisen due to the poor environmental track record of most mining companies.

Mining's greatest threat to groundwater is pollution from drainage of mine tailings. Tailings are the residue remaining after benefication of the ore. Drainage from tailings may consist of process water present at the time of disposal or acidic water caused by percolate passing through tailings undergoing oxidation.

Acidic mine drainage pollution is characterized by a low pH and elevated concentrations of heavy metals affecting both surface and ground waters. The most commonly associated minerals are sulfur, iron, copper, zinc, silver, gold, cadmium, arsenic, and uranium.

One method to prevent groundwater contamination is to place tailings in an engineered waste containment facility designed using the principles employed for modern municipal and industrial landfills. Design of an engineered containment system consists of reducing the leakage to a negligible amount so that the only important contaminant transport mechanism is molecular diffusion. Recent studies sponsored by USEPA have shown that modern landfill liners do perform as intended and have very low leakage rates typically less than 30 L/ha-d (1 mm/yr). However, mine tailings are very different than municipal waste and stabilized hazardous waste placed in industrial landfills. Thus the lining systems used for municipal and industrial waste perform differently much more when they are exposed to mine drainage. In fact, an extensive review of literature has revealed no case studies regarding the environmental performance of engineered containment facilities for tailings. Therefore, efficiency of the lining systems used for mine waste containment must be assessed in order to make responsible decisions regarding mine waste management.

Geosynthetic materials must demonstrate resistance to chemical degradation while in contact with aggressive chemicals in waste management facilities. Waste management facilities are designed for active lives of 30 years or more. However, the success of a landfill management depends not only on active service life but also conditions of the site after closure. Therefore, the barrier systems must also be effective after the closure period. This issue is more critical for non-degradable waste with low or no organic content such as mine wastes. The effectiveness and lifetime of lining systems are more crucial for these types of wastes.

During the past 20 years, a variety of polymers have been used for the manufacturing of geosynthetics that are used as landfill liner materials. The intrinsic durability of geosynthetic materials depends upon the polymer, the auxiliary compounding ingredients, and the construction and manufacture of the material (Haxo and Nelson 1984). However, the durability can vary greatly with respect to different degradation mechanisms with different exposures.

The principal agents aggressive to polymeric materials are heat, oxygen, moisture, atmospheric pollutants, chemicals, low temperatures, stress and strain, enzymes, and bacteria. In most of the exposures, two or more of these agents act together. The following mechanisms of degradation may be encountered in different exposures: UV degradation, radiation degradation, chemical degradation, degradation by swelling, degradation by extraction, and oxidation degradation (Koerner et al. 1990).

Chemical degradation of the liner must be evaluated before the application. Manufacturers have evaluated many situations of chemical compatibility, and have completed various chemical resistance charts, which list the chemical resistance of common geosynthetics against some chemicals. However, there are some circumstances that these charts are useless and specific testing is required for these cases, these circumstances are as follows: when the chemical is not a single-component material and possible synergistic effects are unknown; when the composition of the resulting chemical is simply unknown; when the geomembrane is not a single-component material but is made from a blend of materials; when the geomembrane is modified at the seams with material that is different from that of the geomembrane sheets; when the containment must function over a very long period and the leachate may change over time during the course of the service lifetime; when untested circumstances, such as extreme heat or cold conditions, exist at the particular site; when the chart or table does not list new types and formulations of geomembranes (Koerner 1998).

The circumstances listed above are confronted in many waste management and disposal facilities. Therefore, evaluation of the chemical resistance of geosynthetics against specific waste liquids is a necessity. There are four important decisions to be made for chemical resistance tests: the selection of the particular liquid to be used, the precise details of the exposure (incubation), the type of specimen testing, and assessment of the testing results (Koerner 1998).

The selection of the liquid is case specific and depends on the study. The other three decisions may be made according to the chemical compatibility testing procedures established by EPA, or ASTM, or some modifications of these procedures. EPA has established procedures for evaluating chemical resistance of membrane liners. The method identified as Method 9090 has been in use since the early 1980's (Landreth 1990). Besides this method, ASTM Committee D-35 has developed another standard designated by D-5747; "Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids" (ASTM 1998). The ASTM standard does not have any important differences from Method 9090.

Method 9090 is the most common chemical compatibility testing procedure, which is used in determining the effects of chemicals in a surface impoundment, waste pile, or landfill on the physical properties of flexible membrane liner (FML) materials (EPA 1986). In order to estimate the waste/liner compatibility, liner material is immersed in the chemical environment for minimum period of 120 days at room temperature ($23\ ^{o}C$) and at $50\ ^{o}C$ (EPA 1986). The membrane liners are periodically taken from the immersion tanks, and comparison of measurements of the membrane's physical and engineering properties before and after exposure is used to estimate the compatibility of the liner with the waste over time (EPA 1986). According to Method 9090, the following tests are performed on unexposed and exposed samples; tear resistance, puncture resistance, tensile strength, hardness, elongation at break, modulus of elasticity, volatile content, extractable content, specific gravity, ply adhesion, hydrostatic resistance.

The main objective of this study is to assess the compatibility of lining system materials and mine waste liquids, with the intent of determining if materials used for lining systems will function as intended when they are exposed to mine waste liquids. The second objective is to predict the lifetime of lining system materials by extrapolating the experimental behavior to site-specific conditions.

3. PROCEDURES AND METHODS

Chemical compatibility studies begin with an incubation period accompanied with the periodical tests used to quantify the changes in the performance of geosynthetic material after exposure to the waste liquid. In this study, a modified version of Method 9090 was used to assess the chemical compatibility of geosynthetic materials that are used in waste containment facilities.

In this study, a variety of lining system materials (geomembrane, geotextile, and geocomposite) were exposed to synthetic acidic mine drainage solution and two control solutions. Geosynthetic materials were immersed in the chemical environment for a period of 15 months at 20 ^{o}C, 40 ^{o}C and 60 ^{o}C. Three different chemical environments were used for the exposures: Control I (low pH, no metals solution), Control II (Deionized water) and synthetic acidic mine drainage (low pH, high metals solution).

During exposure, samples were periodically taken from the immersion tanks, and physical and engineering properties of geosynthetics were tested to monitor the effects of the liquids on engineering properties. Once the relative impacts of mine drainage on geosynthetic materials are known, decisions can be made regarding the suitability of various types of containment system elements that will be exposed to mine waste liquids. In addition, precautions can be taken according to life time expectance of these elements and guidelines can be prepared regarding appropriate test methods for chemical compatibility testing with mine waste liquids.

White and Venschoor (1990) criticize Method 9090 by stating that the temperature and exposure times are selected arbitrarily, and reflect the need for a test, which is not expensive and will not delay a construction project for a long time. They also state that the test was never intended to be used as a true life time prediction tool, and the resulting data is not sufficient to make a prediction due to the short exposure duration (120 days), and two temperatures (23 and 50 ^{o}C), which is not sufficient to produce Arrhenius shift factor curve (White and Verschoor 1990).

In this study the following modifications were performed to overcome the drawbacks explained by White and Verschoor: (1) three temperatures (20, 40, 60 ^{O}C) were used, (2) incubation period was extended to 15 months, (3) two control solutions were used in addition to the testing solution, and (4) additional tests were performed such as melt flow index test and infrared spectroscopy analysis.

The geosynthetics used in this study were very similar to the ones that are commonly used in waste containment facilities. These geosynthetics are listed as follows: geomembrane (DURA

SEAL HD), 60 mils, HDPE; geotextile, (GEOTEX 651), nonwoven, medium weight (90 mils, 220 g/m^2), polypropylene; geocomposite for drainage (GSE Fabrinet) consisting of HDPE geonet and nonwoven polypropylene geotextile (285 g/m^2).

These geosynthetics were cut as rectangular coupons and were hung on stainless steel frames without contacting each other. These frames were then placed in stainless steel tanks (or plastic tanks for control solutions), which were equipped with mixers and heaters to achieve the planned incubation conditions. As stated above, three different chemical environments were used for the exposures: Control I (low pH, no metals solution), Control II (Deionized water), and synthetic acidic mine drainage (low pH, high metals solution). The composition of the synthetic mine drainage solution was determined after a literature review of reported acidic mine drainage compositions. The acidic mine drainage composition used in this study is given in Table 1.

Table 1. Composition of the synthetic acidic mine drainage

In addition to the synthetic acidic mine drainage solution, deionized water and a solution which does not contain metals but has the same pH as the synthetic acidic mine drainage solution were used as two controls. The purpose of the second control set was to observe any changes due to the presence of metals in the exposure. Figure 1 summarizes the overall testing plan used in this study.

Figure 1. Testing plan

During exposure, samples were periodically taken from the immersion tanks, and engineering properties of geosynthetics are tested. The following tests were performed on unexposed and exposed samples: thickness, mass, tear resistance, puncture resistance, tensile strength, elongation at break, modulus of elasticity, melt flow index test, transmissivity test (for geotextile and geocomposite), permittivity test (for geotextile) and infrared spectroscopy analysis, which is a special tests used for the detection of degradation in polymer science.

All tests are performed monthly except melt flow index test and infrared spectroscopy test. These tests are the only tests that are not performed in the UW-Madison Geotechnical Laboratory but sent to a polymer testing laboratory. Melt flow tests are performed in every three months and infrared spectroscopy tests are performed in every six months.

ASTM procedures were followed in these tests. The designated ASTM numbers of the tests are presented in Table 2.

Table 2. Tests performed for chemical compatibility assessment

Test	Standard Used for the test
Wide width tensile strength	D4885-88
Puncture strength	D 4833-88
Trapezoidal tear Strength	D 4533-91
Thickness	D 5199-91
Transmissivity test	D4716-87
Melt flow index test	D1238-95

During installation, geomembranes are carefully field tested for defects as part of quality control programs. As a result, geomembrane failures are almost always related to the formation of defects after construction, i.e., a hole, tear, or open seam. Thus, the emphasis in this study was on changes in mechanical properties that relate to puncture resistance, tearing, and wide-width strength.

In addition to mechanical testing, tests like melt flow index test and infrared spectroscopy test were performed, which would help to detect molecular changes in the polymer structure.

The primary function of the geotextile used in a lining system is to cushion the geomembrane and to filter leachate before in reaches the drainage element. The geotextile used in this study was tested for mechanical properties, permittivity and in-plane transmissivity. In-plane transmissivity test was also perfomed with the drainage geocomposite.

4. RESULTS AND DISCUSSION

Before presenting the results up to date, it should be stated that exposure is continuing for all three sets. Six months of exposure was completed in September 2001 for acidic mine drainage exposure. Wide width test, puncture test and tear test results for mine drainage set are presented in Figure 2 and Figure 3 separately for geomembrane and geotextile.

Comparison of exposed and unexposed wide-width tensile strengths of the geomembrane samples of acidic mine drainage set suggests that the HDPE geomembrane has slightly deteriorated due to exposure. This deterioration was not easily detectable with puncture and tear test results due to the high standard deviations recorded in these tests. Puncture and tear strength values recorded during the exposure were fluctuating within the high standard deviations of unexposed samples.

Melt flow index (MFI) results also suggested a certain amount of degradation of the geomembrane. MFI of unexposed HDPE geomembrane was determined as 0.247 g /10 min. Higher MFI results were recorded after three months of exposure. MFI increased up to 0.269 g/10 min for the samples that were exposed to mine drainage at 60 ^{o}C. Higher MFI suggest lower molecular weights in polymer structure causing lower viscosities. The increase in MFI is expected to be higher after six months of exposure. However, these tests are not completed yet.

As it is seen from Figure 3, the test results of exposed geotextiles have still fluctuations mostly within the standard deviation of unexposed samples. It was observed during the tests that failure in geotextile samples were mostly dominated by local failures at certain weak points of the samples other than complete failures of the samples. This made it more difficult to detect any degradation.

In Figure 4, transmissivity results for the geocomposite (i.e., the geonet component) are presented for samples exposed to acidic mine drainage at 60 ^{o}C. As it is seen in Figure 4, significant reductions in transmissivity of the geocomposite (i.e., the geonet component) exposed to acidic mine drainage at 60 °C were observed. Reductions in transmissivity values were not as much in other exposures and fluctuations are in a narrow range.

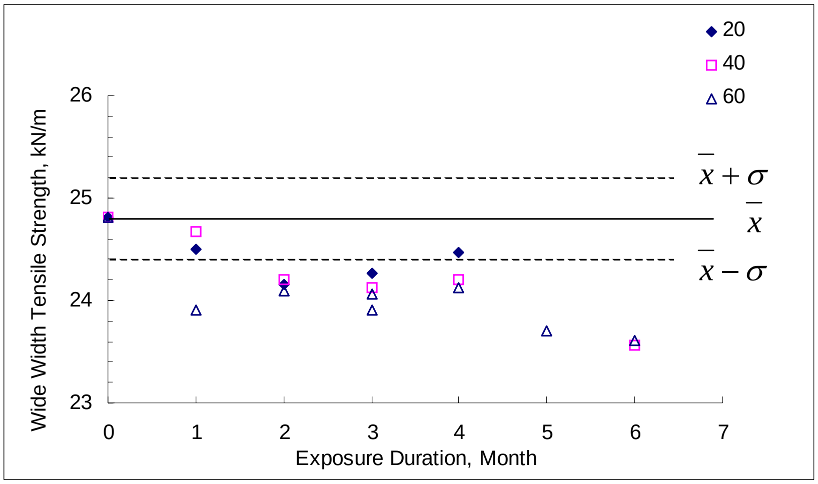
5. CONCLUSIONS AND RECOMMENDATIONS

Even though exposure and experiments are continuing, following preliminary conclusions can be drawn for the first six months of the study.

HDPE geomembrane has slightly deteriorated due to acidic mine drainage exposure as it was concluded from wide width test and melt flow index results. This deterioration was not easily detectable with puncture and tear test results due to the high standard deviations recorded in these tests.

For geocomposite specimens, significant changes in physical and engineering properties were not detected due to high variability in the test results of unexposed samples. However, reductions in the transmissivity results were detected for geocomposite specimens. No noticeable changes were observed in geotextiles.

It should also be stated that these results and conclusions will be updated with continuing testing.



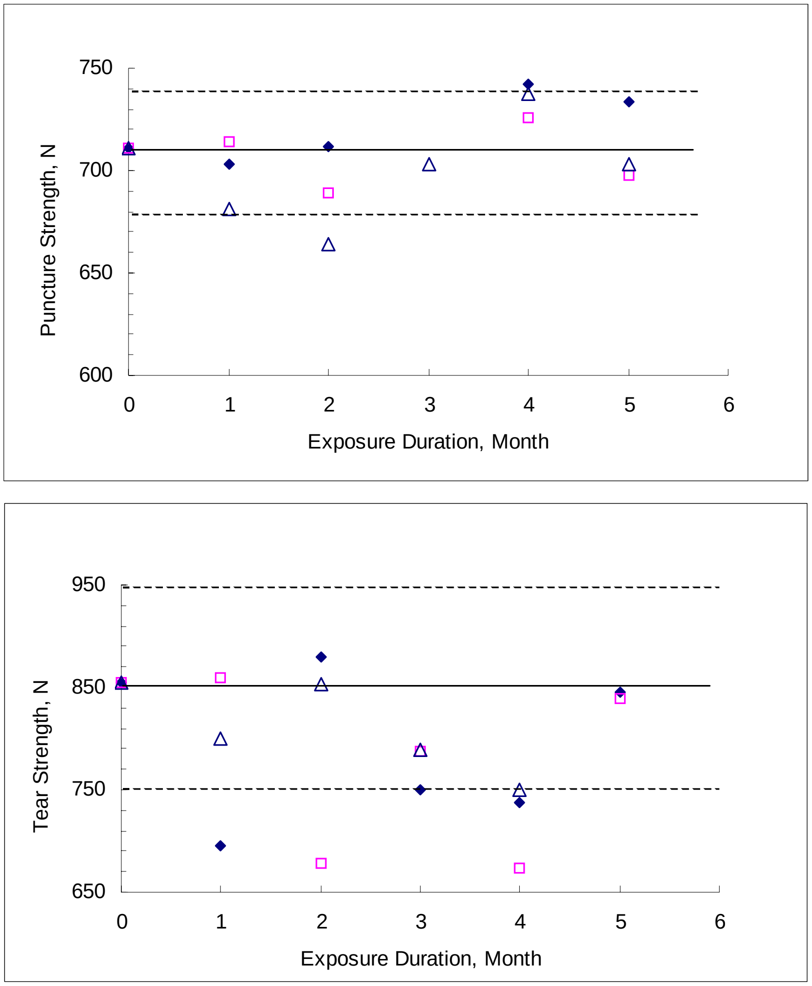
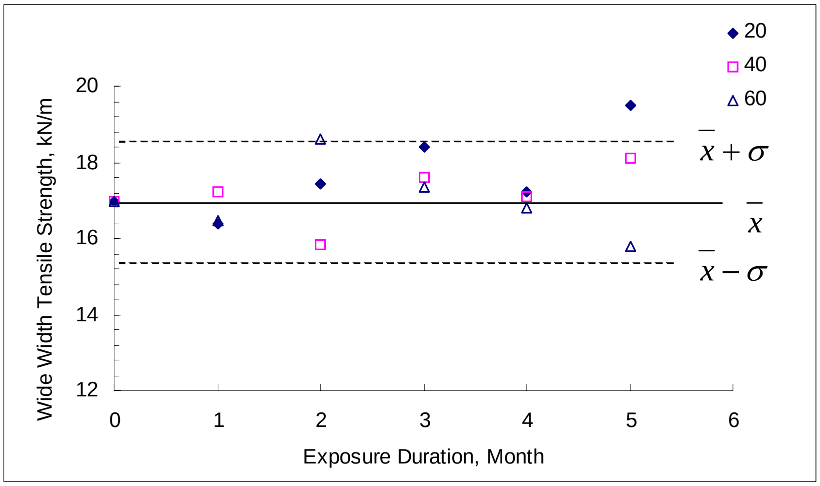


Figure 2. Test results for geomembranes in mine drainage at 20, 40 and 60 ^{o}C



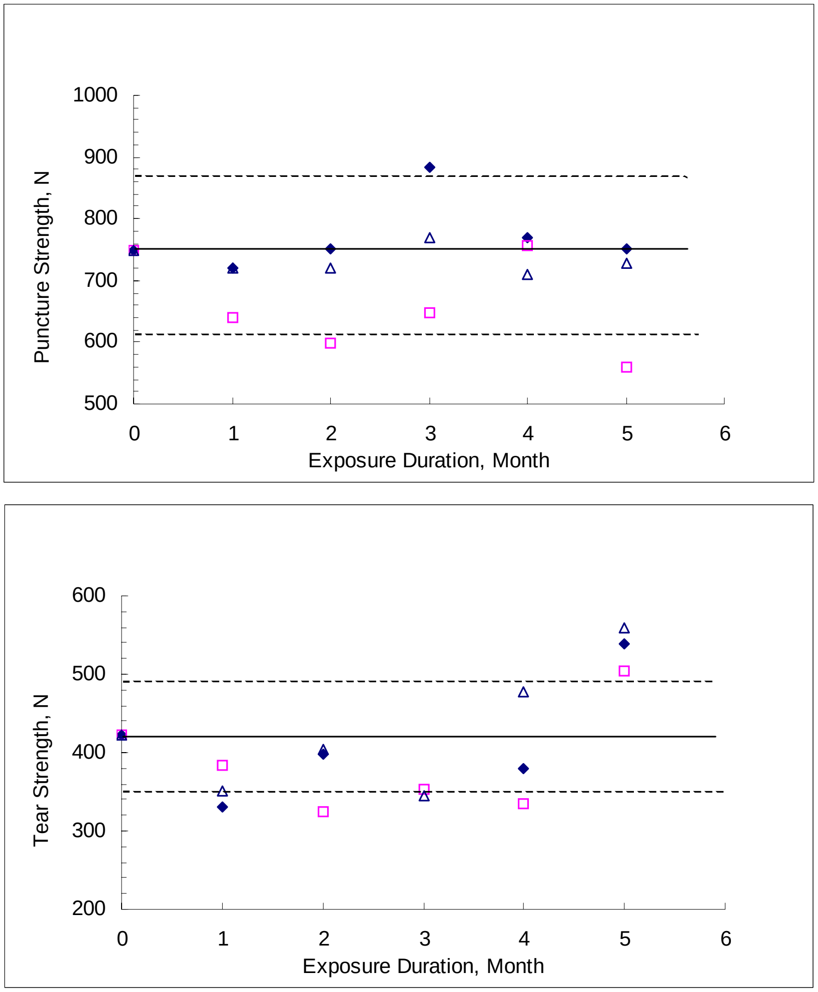
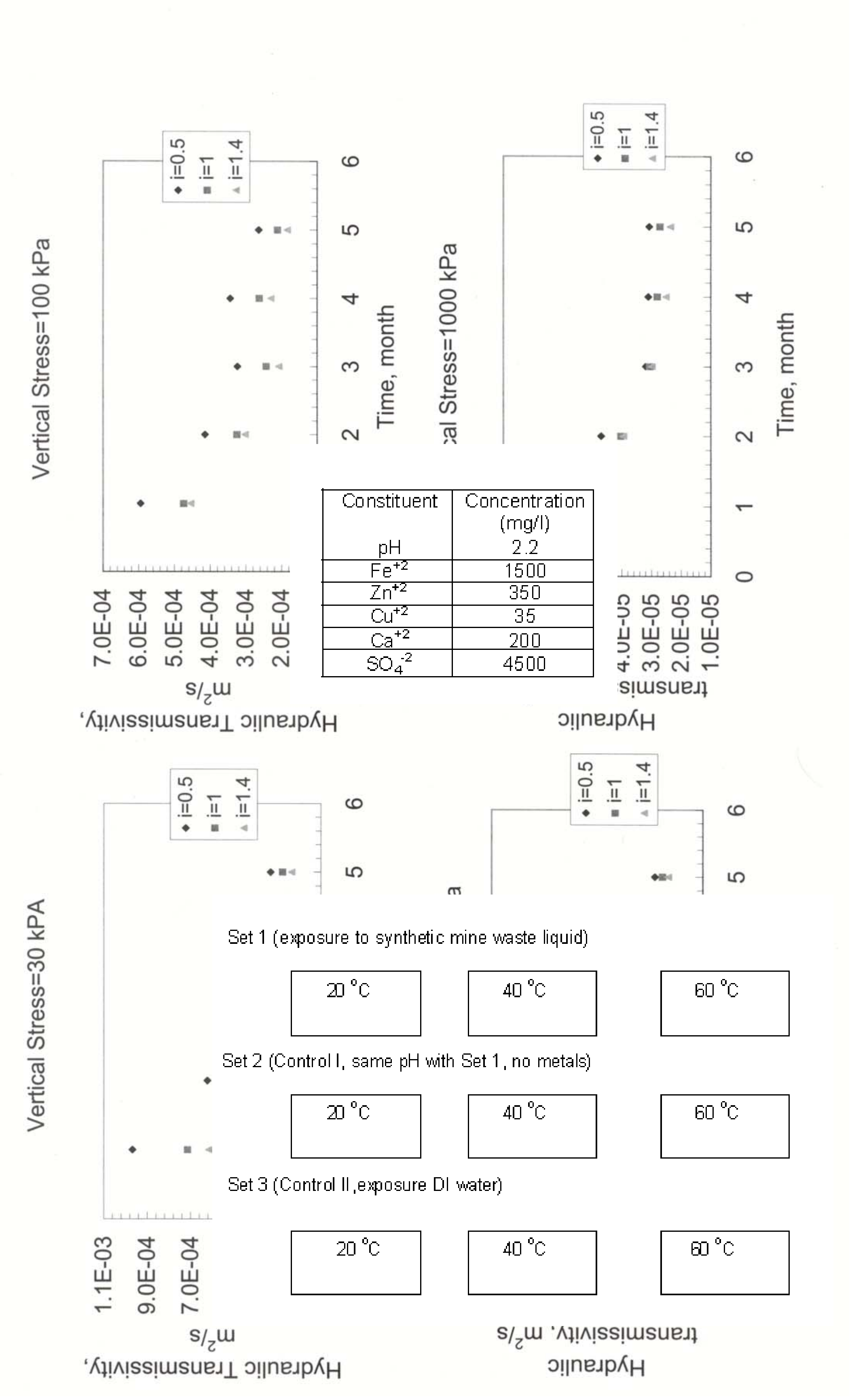


Figure 3. Test results for geotextiles in mine drainage at 20, 40 and 60 ^{o}C



Constituent	Concentration (mg/l)
pH	2.2
Fe^{+2}	1500
Zn^{+2}	350
Cu^{+2}	35
Ca^{+2}	200
SO_4^{-2}	4500

Set 1 (exposure to synthetic mine waste liquid)

20 °C 40 °C 60 °C

Set 2 (Control I, same pH with Set 1, no metals)

20 °C 40 °C 60 °C

Set 3 (Control II,exposure DI water)

20 °C 40 °C 60 °C

Figure 4. Transmissivity results for geocomposite sample for acidic mine drainage at 20, 40, and 60 °C

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