CHAPTER 8

PROTECTIVE COATING FOR GABION WIRES AGAINST WEATHERING ELEMENTS AND SITE CONDITIONS

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8.1 INTRODUCTION

Gabions are one of the most essential elements in the geotechnical field for their versatility and strength in slope stabilization. According to BS 8002:2015, gabions are rectangular large cages or baskets made of either steel wire or square welded mesh, and are usually filled with stones. Besides slope stabilization, gabions have been widely used for various purposes, including closing of river banks, road construction, landslide consolidation and hilly terrain reclamation [1].

The steel wires of the gabions are treated with various anti-corrosion materials such as plastic coating, zinc-aluminum alloy and heavy zinc coating to provide extra durability [2]. However, since gabions are used for various purposes, they are constantly under different exposure conditions. The effectiveness and durability of the protective coating may vary due to the different environment. They can be in dry or soaked condition when they are used as flood walls and bank protection. However, both conditions would still expose the gabions to solar ultraviolet (UV) radiation. UV radiation under the combined influence of heat, chemical agents and mechanical stress could degrade the plastic-based or organic coating [3]. When a plastic coating material is degraded, water molecules can penetrate through the coating and attack the substrate, causing it the be weaken internally.

The objectives of this study are to determine the anti-corrosion characteristics of a proprietary plastic-based protective coating for gabion steel wire and to identify the rate of corrosion under various weathering conditions (dry, soaked and buried). Study was conducted to examine the effectiveness of a proprietary plastic-based protective coating for gabion wires against corrosion in exposure to weathering elements. Material is based on the Industrial Collaborator, i.e. United Glory Industry Sdn. Bhd, Batu Pahat recommendation and supply. Weathering elements examined include UV exposure and heat in both dry, soaked and buried conditions. The effectiveness of the protecting coating would be determined by tensile strength, elongation at break, elastic modulus at 100% elongation and abrasion resistance tests. Material samples are subjected to natural weathering for 750 hrs.
8.2 LITERATURE REVIEW

The early gabion baskets are made of plant materials which limited the durability. In 1879, an Italian company revolutionized the construction of gabion baskets and replaced with wire mesh, which later became the modern gabion baskets as used today [4].

Since gabions can be applied in both civil and hydraulic engineering, it implies that gabions will be found in or on soil as retaining structures, along the streams and sea coast as erosion control structures. With such wide applications, the gabions must be built durable enough to withstand all possible site conditions that might weaken and damage the structure.

The durability of the gabions relies greatly on the durability of the wire mesh as Nešović et al. (2015) discussed that limited life of the wire basket is the major drawback of gabions [5]. To overcome, present coating technology which applies a polyvinyl chloride (PVC) or cross-linked polyethylene (XLPE) guaranteed the durability of gabions [2].

GABIONS

Gabions can be formed by hexagonal woven wire mesh or welded wire mesh. For wire mesh, the materials must satisfy high mechanical properties and corrosive resistance. Galvanized wires are normally used to reduce corrosion. The wires may be also coated with PVC or other materials to prevent corrosion which can damage the wire mesh [4]. When individual units are stacked, it forms a reinforced cellular structure, known as gabions wall.

CORROSION

Corrosion is defined as electrochemical degradation which involved oxidation and reduction reaction, occurring at the metal-solution interface. In corrosion, metal undergoes oxidation (anodic reaction) and species from the solution such as oxygen (cathodic reaction) undergoes reduction [6]. Generally, corrosion causes wearing of metal gradually by chemical or oxidizing processes. In the presence of atmospheric polluting agents such as hydrochloric acid (HCl), sulphur dioxide (SO₂), ammonia (NH₃), and particulates like dust, dirt and soot, corrosion can be further aggravated and alter the course of corrosion [7]. Besides atmospheric polluting agents and particulate matter, Bierwagen (1996) also suggested other global and local environments that affect corrosion, including humidity and its cycling, salts, UV exposure, temperature cycles, bacterial growth, pH, standing water and presence of other chemicals [8].

CORROSION CONTROL

Corrosion control is a measure to reduce the rate of corrosion by preventing the occurrence of chemical reactions that damage the metallic state [7]. Coatings play a significant role in corrosion control which are later applied in major corrosion-control methods include sacrificial protection and barrier protection, but very often they are used in conjunction [6].

a) Sacrificial Protection

Sacrificial protection, cathodic protection or zinc-rich coating is a method to prevent corrosion galvanically. Zinc-rich coatings which contain high amount of zinc dust are serve as the anode of an
b) Barrier Protection

Barrier protection is usually applied in the form of impermeable coatings to suppress the transmission of oxygen and water from contacting the metal surface, to a sufficient extent that corrosion may be prevented [9]. These barriers are commonly applied in the form of organic coatings [6]. The principal element in barrier protection is the use of molecularly dense films (highly uniform cross-linked thermosets and relative crystalline thermoplastics). To give coating systems of high electrical resistance that maintain adhesion even under wet conditions, non-hydrophilic components and lamellar pigments is added into the coatings.

Polymeric Materials

Large molecules which are made up of many smaller units joined together to create a long chain often known as polymer. Synthetic polymers are the combination of long molecular chains and organic connections obtained through natural products processing or synthesis of primary materials from oil, gas, or coal.

Many corrosion protection methods have been developed to protect metals from the environment, however organic coatings are the most prominent among all [6]. In organic coating, corrosion protection effect is achieved by the barrier nature of polymer to the passage of oxygen and water. Sangaj & Malshe (2004) mentioned that organic coatings are the natural choice for corrosion protection due to low cost, versatility and aesthetic attributes [7]. The effectiveness of organic coatings as barriers to protect steel is when the coatings cover essentially the substrate surface wholly and the layer remains intact in service. When there is no complete coverage of the substrate or the layer ruptured, the permeability of the barriers is compromised, and corrosion can be initiated [10].

Among the synthetic polymers available, polyvinyl chloride (PVC) exhibits attractive anti-corrosion properties including good mechanical properties (i.e. elastic modulus and shock adsorption), as well as chemical properties which resists to acidic, alkali and oxidative environments [11]. The drawback of PVC is the high sensitivity towards UV radiation [12]. Despite that, its wide availability at low cost promote the application in various industrial processes, including corrosion protection [11].

WEATHERING OF COATINGS

Weathering is a universal phenomenon that occurred in plastic materials when they are subjected to external environments and exposed to the outdoor thermal, radiation moisture and chemical conditions [13]. The effects of weathering can be shown in various forms including change in colour, texture and dimensions, weakening of molecular chains, altering the mechanical, electrical and physical properties. Worse, weathering may cause materials to completely deteriorate. Weathering factors include heat, light, oxygen, water/humidity and pollutants [14].
a) Photodegradation

Photodegradation is the process where a photodegradable molecule is degraded by the absorption of photons, specifically those wavelengths found in sunlight, such as infrared radiation, visible light, and ultraviolet light. The degradation process causes photo dissociation (breakup of molecules into smaller pieces by photons), permanent change of molecule’s shape and addition of other atoms or molecules via oxidation reaction on photodegradation or photooxidation [15]. Among the solar radiations, UV radiation is the most destructive to paint and coating system because of the high frequency (or short wavelength) [13].

b) Water and Humidity

When polymer composites are exposed, they mostly absorb small yet potentially damaging amount of moisture from the surrounding environments. It poses negative impacts to the material by changing the dimension (swell) and decreasing the glass transition temperature (polymer becomes hard and brittle, behave like glass when the is cooled below this temperature) and ultimately weaken the mechanical and physical properties [16]. Farshad (2006), Hardcastle (1999) and Wypych (2013) further explain that upon drying, contraction occurs at the surface layer but is hindered by the underlying layers which still in swollen state [14,17,18]. This causes tensile stresses to develop on the material’s surface and lead to cracking.

c) Temperature

Under high temperature, thermal stresses generally cause thermal degradation and ultimately result in the formation of thermolysis product [19]. The temperature is mainly referred to the heat as higher temperatures cause reaction kinetics and ultimately degrade the polymers [14]. When additional heat is applied to a material, the vibrations of atoms increased.

During the outdoor service, another important aspect to consider is the cycling thermal that occurs to the coating materials. The difference in temperature during afternoon and night in typical Malaysian weather is significant. Coating material that constantly undergoes the temperature cycling can cause delamination as the substrate and coating often have different thermal coefficient. Coating may crack upon thermal cycling if the elasticity is insufficient [20].

d) Acid Attack

Acids consist of inorganic mineral acids which disassociate completely in water, organic acids which partially disassociate in water are claimed to aggressively attack most coating systems. At outdoor atmosphere, acidic gases such as sulphur dioxide (SO₂) and hydrogen sulphide (H₂S) react with the atmospheric moisture either by precipitation or condensation to form acids. Condensation attacks the coating more aggressively compared to precipitation. During daytime, substrate get warmed and evaporates the condensed moisture (containing acidic constituents) on the coating surface. As moisture evaporates, the acid residue becomes concentrate attack the substrate. On precipitation such as acid rain, it is diluted by successive rainfall or even washed from the surface [21].
e) **Alkaline Attack**

Saponification is considered the most widespread type of alkaline attack by attacking the ester linkage of drying oils used in most oil-base coatings and alkyds. The ester linkage in the drying oil is cleaved by the hydroxyls (OH-) to form an organic acid and alcohol. The flexibility is reduced by the bond breaking and embrittles the film, ultimately leads to resin deterioration. Although all coating resins containing ester groups are susceptible to such attack, some of those highly crosslinked and formulated with epoxy resins and other materials resins can sterically hinder the ester group, protecting it from alkali attack. Saponification and hydrolysis are similar, but the saponification reacts much faster and more debilitating [21].

f) **Sea Water**

The effect of sea water does not show a direct effect on the degradation of polymeric coating materials or degradation mechanism such as photodegradation. Rather, it shows similar effect to exposure of water and humidity. The overall performance of polymeric materials in sea water is great. It shows satisfactory durability for marine applications [22].

However, the effect of water and humidity on the degradation of polymeric coating materials is still a concerned. Once the coating is degraded and deteriorated, the coating loss the barrier properties and seawater is in direct contact with the steel substrate. The additional sodium chloride, sulfate, bicarbonate, bromide and fluoride ions corrode metal more aggressively compared to water, ultimately shorten the durability of the coated steel [23].

**WEATHERING TEST**

Weathering is a scientific process of exposing polymeric materials to a natural environment or accelerated in a weathering chamber. Weathering techniques generally involve comparative technique which expose materials together with a benchmark material of known performance or measure the change in properties of an exposed material [13].

Weathering test is divided into natural and accelerated. Accelerated weathering is conducted in the laboratory with controlled artificial light sources and conditions, whereas natural weathering is performed outdoor in large fields with real sunlight and non-controlled exposure parameters [24].

However, the correlation between accelerated and natural weathering test results are still highly debatable as the approaches in accelerated exposure of using higher temperature, shorter wavelengths of light and higher light intensity can lead to reduce in correlation [25]. Longer period testing is useful in reduction of potential errors in prediction and further experimental verification is required [26].

Weathering test is a variable science as the weather is variable, hence the exposed materials are facing constant change of environment [13]. Cited Burroughs (1998), based on climatological statistics, concluded the climate data is hardly contains predictable cycles which can be used in making decision for the prediction of service life. Grossman (2010) described the comparison between a constant condition in accelerated test and variable condition in natural test is hardly valid. Therefore, weathering data is not absolute but comparative data [27].
8.3 MATERIALS AND METHODS

This section serves as a guideline to ensure a systematic execution of the study. Every procedure in this project is shown step-by-step, which also ensured the objectives of the study were achieved. It also discusses about the experimental procedures, designs, modifications done, methods and materials. The overall research methodology flow chart of this research was shown in Figure 8.1.

Durability of gabions is enhanced by providing various protection to the steel wire, such as heavy galvanization or application of protective coating. However, due to the versatility of gabions, they can be applied in various fields under different weathering conditions. In this study, the focus is on adopting natural/outdoor weathering testing to determine the effect of weathering on the proprietary plastic-based coating by evaluating their mechanical properties change. The mechanical properties evaluated included tensile strength, elongation and abrasion resistance.

![Flow Chart]

Figure 8.1: Overall research methodology flow chart of this research

<table>
<thead>
<tr>
<th>No.</th>
<th>Proposed Site Conditions</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unconditioned</td>
<td>Typical daytime</td>
</tr>
<tr>
<td>2</td>
<td>Soaked in water</td>
<td>Applied in river banks, dams and flood prone areas</td>
</tr>
<tr>
<td>3</td>
<td>Soaked in acid (pH 4.5)</td>
<td>Applied in contaminated rivers, peat soil area</td>
</tr>
<tr>
<td>4</td>
<td>Soaked in alkali (pH 8.0)</td>
<td>Applied in contaminated rivers near industrial area</td>
</tr>
<tr>
<td>5</td>
<td>Soaked in saltwater</td>
<td>Applied in coastal area</td>
</tr>
<tr>
<td>6</td>
<td>Covered with wet soil</td>
<td>Buried in normal river area</td>
</tr>
<tr>
<td>7</td>
<td>Covered with acidic soil (pH 4.5)</td>
<td>Buried in peat soil area</td>
</tr>
<tr>
<td>8</td>
<td>Covered with alkali soil (pH 8.0)</td>
<td>Buried in alkali metal polluted soil</td>
</tr>
<tr>
<td>9</td>
<td>Covered with marine deposits</td>
<td>Buried in coastal area</td>
</tr>
</tbody>
</table>
PROPOSED SITE CONDITIONS

Site conditions refer to the natural environment that might be experienced by the gabions during their applications. The proposed site conditions included the exposure possibilities, recreated in outdoor condition to examine how these conditions affect the weathering rate of the protective coating. Table 8.1 shows how the proposed conditions were related to real conditions.

TEST SAMPLES

The test samples of proprietary plastic-based coating were provided by United Glory Industry UGI Sdn. Bhd. The geometry and dimension of the test samples were based on the mechanical properties testing carried out after every 250 hours of exposure for total of 750 hours. Each test required samples of specific dimensions to be installed in the test equipment.

a) Tensile Properties Samples

The proprietary plastic-based coating for tensile strength and elongation samples were manufactured using hot-pressing method. The average thickness of the sheet was 1.60. Dimensions for the samples used were modified from specimen type 5 as suggested in BS EN ISO 527-3:1996 (Figure 8.2).

![Figure 8.2: Geometry and dimensions of the tensile test samples](image)

b) Abrasion Resistance Samples

The abrasion resistance was determined using the textile abrasion tester as described in BS EN ISO 12947-3:1998. The proprietary plastic-based coating for abrasion resistance samples were manufactured using milling method. The average thickness of the sheet is 1.40 mm. The test samples were cut into circular shape with diameter of 38 mm using a sample cutter (Figure 8.3).

![Figure 8.3: Geometry and dimensions of the abrasion resistance samples](image)
OUTDOOR WEATHERING TEST

The outdoor weathering test adopted the direct exposure method, which was conducted by exposing test samples on an exposure rack. The test samples were subjected to elements of natural outdoor environment, which primarily included solar radiation (UV), moisture and heat. The test was carried out for 750 hours, starting from 22nd October 2017 to 25th November 2017, with samples retrieved for tests every 250 hours to run the tensile and abrasion resistance test.

The outdoor weathering test was conducted on an empty field located in between Block F and Block G in Universiti Tun Hussein Onn Malaysia (UTHM) Pagoh Campus (2.149N, 102.731E) as shown in Figure 8.4 and 8.5. The testing site was an open field and received sunlight throughout the day without obstruction by nearby structures. The climatic data were monitored.

EXPOSURE RACK AND SET-UP

A steel exposure rack was fabricated to hold the test samples throughout the exposure period. The rack was designed to be tilted with exposure angle of 45° from the horizontal (Figure 8.6).

In the set-up, monitoring systems were included to observe and record the changes in the variables during the weathering test. The ambient temperature and relative humidity of the test site were measured and recorded automatically by Elitech GSP-6 Temperature and Humidity Data Logger. The rainfall intensity was monitored daily by ClimeMET CM1088 Rain Gauge and data were recorded in the ClimeMET CM5011 Rainfall Chart. Complete set-up was shown in Figure 8.7.

SAMPLES HOLDER

During weathering, samples were placed on the rack to receive maximum exposure to UV, heat and moisture. All 9 exposure conditions were simulated in separate sample holders to avoid cross-contamination of acidic, alkaline and salt solution vapours.
Samples for tensile properties test were placed in a clear PVC zipper bag (320 mm X 220 mm) (Figure 8.8). The holder was watertight and chemical-resistant. Test samples were externally secured with paper clips to prevent them from overlapping with one another and reducing exposure surface. The opening was sealed to prevent leakage and contamination.

Abrasion resistance samples are placed in clear acrylic container (200 mm X 120 mm X 35 mm) (Figure 8.9). The container was chemical resistant and provided with clear cover to minimize the contamination of site conditions. Samples were arranged to prevent any overlapping and to maximize the exposure area.

EXPERIMENTAL WORKS

A set of test samples were tested for tensile properties (tensile strength, elongation at break and elastic modulus at 100% elongation) and abrasion resistance without undergoing any exposure test, i.e. control samples. This was to provide the base results for comparison with the exposed test samples.

Tensile test: After the test samples were exposed to weathering outdoor, the test samples are collected and subjected to the tensile test. Tensile test was carried out using the GOTECH AI-3000 universal testing machine with 5 kN load cell according to EN ISO 527-3:1995. The test speed was set at 100±0.5% mm/min. Dedicated software analyzed and calculated the tensile strength and modulus of elasticity at 100% elongation automatically. Stress-strain graphs were provided as well. The elongation at break was measured using the machine provided extensometer.

Abrasion resistance: Abrasive resistance is a test carried out to assess the mass loss from the surface of the coating materials when abraded against an abradant. This test was carried out according
to BS EN ISO 12947-3:1998 using a Shirley Developments Abrasion Tester Mark III. Modification was done to replace the fabric sample with coating material and the fabric abradant with abrasive paper (Figure 8.10 and 8.11).

The test samples were weighed to obtain the original mass to 0.01 g accuracy. The circular test samples were then mounted on the sample holders and subjected to 12 kPa top weight. The circular abradants of 140 mm diameter 280-grit silica carbide abrasive papers were mounted in the abradant holders. The test samples were subjected to 1000 rubs against the abrasive medium in a translational movement, tracing a Lissajous figure. The sample holder rotated freely around its own axis perpendicular to the plane of the test sample. The abradant was replaced after every 1000 rubs.

8.4 RESULTS AND DISCUSSIONS

Climatic parameters monitored throughout the natural weathering included ambient temperature, relative humidity and rainfall intensity. All parameters were monitored from 23th October 2017, 9.00 a.m. to 25th October 2017, 9.00 a.m. Samples are being tested for the change in abrasion resistance and tensile properties according to modified BS EN ISO 12947-3:1998 and EN ISO 527-3:1995 respectively every 250 hours interval. The test results were compared between the control (unexposed) and the exposed samples. This helps to understand how each site conditions and natural weathering can affect the durability of the PVC coating material.

ABRASION RESISTANCE

Coating material with abrasion resistance is described as the ability to protect substrates from wear by friction, hence protecting the aesthetic appearance and durability under constant use. Therefore, the less wear mass loss indicates better abrasion resistance. Mass loss percentage was calculated using Equation 8.1.

\[
\text{Mass loss percentage} = \frac{(\text{final mass} - \text{initial mass})}{\text{Initial mass}} \times 100
\]

Figure 8.12: Net mass loss percentage of different samples

750 hours of outdoor exposure may not be significant compared to 2500 hours of accelerated UVA exposure or 4000 hours of accelerated Xenon Arc exposure as required in BS EN 10223-3:2013 for organic coated gabions. Hence, the mass loss percentage across 750 exposure hours was averaged and shown in Figure 8.12 to understand which site conditions have the most effect on the abrasion resistance of PVC coating.
The relatively lower mass loss percentage shown in seawater, alkali and water (soaked) might due to the lack of heat build-up in samples and biofouling of sample surface as discussed in a study by Pegram (1989) [28]. Samples exposed to sunlight undergo heat build-up which results in the samples reaching significantly higher temperature than the surrounding air. When air temperature around 26°C to 36°C during the period of exposure, the samples’ surface can be much higher, as much as 60°C than that of the surrounding air. The study also mentioned all materials exposed to the sea undergo fouling. Fouling leads to the formation of biofilm which encourage algal growth. Ultimately, the biofilm becomes opaque and restrict light availability for photo-oxidation to occur. Samples subjected to acidic condition show relatively higher in mass loss percentage may due to the lack of biofilm formation as optimum pH range for most cultured algae species is between 7 to 9, optimum range is 8.2 to 8.7 [29]. Therefore, algae growth may be prohibited under low pH condition (4.5).

Buried samples generally showed higher mass loss percentage compared to soaked samples. This may due to the higher temperature of sand compared to water when exposed to sunlight as the specific heat capacity of sand is significantly lower than water, 800 J kg⁻¹K⁻¹ compared to 4200 J kg⁻¹K⁻¹. Hence, temperature of sand is relatively easier to raise compared to water, resulting in samples exposed to higher temperature during daytime and lower during non-daytime (greater temperature change cycle). Samples buried in alkali showed the greatest mass loss percentage might due to the above-mentioned factor. PVC under environmental stress crazing conditions was found to have significantly affected in high pH sodium hydroxide (NaOH) solution [30].

**TENSILE STRENGTH**

Samples generally showed decrease in tensile strength as compared to the unexposed samples. The difference in tensile strength recorded for 3 intervals were averaged to obtain the mean and compared against unexposed samples to understand the how different site conditions affect the tensile strength (as shown in Figure 8.13)

![Figure 8.13: Net Tensile strength loss for all samples](image)

The most affected samples were soaked with seawater which experienced a constant drop in tensile strength and recorded the most difference as compared to unexposed samples. However, as compared to Figure 8.12, the results showed samples soaked in seawater to sustain the least mass loss in abrasion resistance test. As Singh et al. (1998) found that the degradation process could lead to development of surface flaws which serve as sites for stress concentration, followed by propagation of mechanical failure [31]. Hence, different sample surface (milled sheet and hot-pressed sheet) may affect the result between abrasion resistance and tensile strength.
MODULUS OF ELASTICITY AT 100% ELONGATION

Compared to the control samples, all exposed PVC coating material showed a reduction in the modulus at 100% elongation. The reduction indicates the loss in material ductility after going through the weathering process as per finding of Real et al. (2003) [32]. The study conducted by Eleni et al. (2011) showed polydimethylsiloxane (PDMS) elastomer to harden after 1 year of outdoor exposure [33]. Similarly, Mendes et al. (2003) reported that un-stabilized high-density polyethylene (HDPE) experienced severe loss in mechanical properties (mainly elongation at break and impact resistance) due to photolysis of hydroperoxides reactions [34]. Ultimately, the behavior changed from ductile to brittle after 2520 hours of natural exposure.

The data for modulus of elasticity at 100% elongation across 750 exposure hours were averaged to visualize (Figure 8.14) the severity of each site condition compared to unexposed samples.

![Figure 8.14: Net modulus of elasticity at 100% elongation loss for all samples](image)

Net modulus of elasticity at 100% elongation loss showed similar trend as compared to net tensile strength loss where samples soaked in seawater experienced the most loss. Samples buried in seawater however do not agree with the trend of tensile strength loss. This may be due to the biological attack by microorganism activity in soil as unknown microorganism growth patches were found on the seawater-soaked tensile test samples.

ELONGATION AT BREAK

The elongation at break for PVC coating samples did not appear to be affected significantly by weathering and various site conditions, in fact, the trend showed an increase of elongation at break as compared to the unexposed samples. Similar variation was found in the study of Merah et al. (2013), where the fracture strain % experienced significant drop for the first month of exposure followed by a slight increase in the second month and remained nearly constant until 18 months of exposure [35]. A study conducted by Naddeo et al. (2004) on spherilene linear low-density polyethylene films showed similar fluctuation in elongation percentage. The higher elongation % may be due to the cross-linking mechanism [36].

Variation in results may also may due to the location of fracture of each sample. The sample subjected to tensile load in the UTM. When the sample broke, not all sample broke within the gauge length (25 mm), where some were observed to be broken beyond the gauge marks, such as at the
clipping point of the extensometer. This may cause the recorded elongation at break to be inaccurate. The data for elongation at break across 750 exposure hours were averaged for the ease of comparison (as discussed in sub-topic of tensile strength and elastic modulus) on the severity of each site condition compared to unexposed samples (Figure 8.15).

The results from tensile strength and elastic modulus at 100% elongation showed seawater soaked samples experienced the greatest reduction as compared to unexposed samples. This result was further verified as the increase in elongation at break of the seawater soaked samples was the least. In contrary, unconditioned samples showed the minimal tensile strength and elastic modulus at 100% elongation loss. The result was verified by the gain in elongation at break. Despite the samples buried in alkali showed the least tensile strength loss and most increment in elongation at break, the result is not verified by a significant loss in elastic modulus at 100% elongation. Hence, the changes in tensile properties showed samples soaked in seawater was to be most affected whereas the unconditioned samples to be the least affected.

The overall durability of PVC coating was evaluated by providing ‘points’ to each site condition based on the performance in each test parameter across 750 H of exposure. Site condition with the least effect on test parameter was given 9, in descending order, and the most effect on test parameter was given 1. The ‘points’ scored for each test parameter were tabulated and summed-up in Table 8.2. Higher total ‘points’ indicates better durability. Hence, the overall durability of the PVC coating was determined as most durable when unconditioned and least durable in acid-soaked and alkali-buried.

<table>
<thead>
<tr>
<th>Site conditions</th>
<th>Abrasion Resistance</th>
<th>Tensile Strength</th>
<th>Elastic modulus at 100% elongation</th>
<th>Elongation at break</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconditioned</td>
<td>6</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>31</td>
</tr>
<tr>
<td>Clear Water (Buried)</td>
<td>8</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>Seawater (Buried)</td>
<td>4</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>Clear Water (Soaked)</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Alkali (Soaked)</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>23</td>
</tr>
<tr>
<td>Acid (Buried)</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>Seawater (Soaked)</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Acid (Soaked)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Alkali (Buried)</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>
8.5 CONCLUSIONS

Despite the short weathering period (32 days of natural weathering), all samples had showed degradation in mechanical properties, including abrasion resistance, tensile strength, elongation at break and elastic modulus at 100% elongation. The data obtained did not show the ‘ideal’ trend of degradation due to external factors such as weather, biological influences and pollutants. Both abrasion resistance and tensile test have suggested two sets of data and estimation. Surface condition of samples was the main factor that lead to such variation. This is because abrasion resistance measures the hardness of surface whereas tensile properties concern the whole structure. Through analysis and comparison with previous works, this study has concluded that:

Abrasion resistance: Samples buried in alkali are the least durable against abrasion as the recorded mass loss percentage was the highest, followed by the samples soaked in acid. The most durable are the samples soaked in seawater (but others did not show significant difference).

This implied the lack of heat built up on seawater soaked-samples helped to reduce the impact of degradation on the samples surface. Besides, biofouling of soaked samples surface appeared to be a barrier to protect against surface degradation by UV and chemical attack. In contrary, buried samples were exposed to relatively higher temperature of sand due to the lower specific heat capacity. The sand that trapped heat acted as a heat incubator which constantly heat-up the buried-samples and with the effect of chemical attacks, greater surface degradation effects were shown.

Tensile properties: PVC protective coating is least durable when soaked in seawater, followed by samples soaked in acid. The most durable was found to be the samples exposed only to natural weathering without the influence of other site conditions. Other site conditions showed moderate effect on the tensile properties and the changes in parameters were similar.

This implied that aside from UV, temperature and humidity, chemical attacks (acid and alkali) has significantly contributed to the degradation of the PVC coating structure through a series of degradation mechanism as discussed. Besides, seawater may contribute to the degradation, depending on the biological and chemical contaminants.

The overall durability of the PVC coating was ranked accordingly: unconditioned (best), water and seawater-buried, water and alkali-soaked, acid-buried, seawater-soaked, acid-soaked and alkali-buried (worst)

8.6 RECOMMENDATIONS

Through this study, some recommendations were found useful in providing improvement to similar study and future works. Although to provide absolute information on the weathering durability of PVC coating could be difficult, however the results can still be indicative of the weathering effects as per the following recommendations:

i. Samples should undergo longer hours of exposure to weathering, i.e. 2 years to show more significant changes in mechanical properties. Short exposure period may lead to fluctuation in mechanical properties due reaction such as cross-linking of polymer.

ii. Evaluation on the durability of coating materials should be conducted on coated substrate to
show more realistic representation and behaviour of the coating material under actual applications.

iii. Sample holder should be of material that resist to weathering, i.e. glass to minimize the possibility of holder experiencing degradation faster than the samples

iv. Accelerated weathering test should be carried out to compare the degradation rate, behaviour and mechanism under controlled environment to correlate with the results obtained in natural weathering test. The comparison of results could suggest the effect of biological influences and pollutants during weathering test.

ACKNOWLEDGEMENT

Appreciation also goes to Mr. Allen Liew from United Glory Industry Sdn. Bhd who is generous to provide financial aid and supply materials for this study. Besides, his rich experience in the industry has guided me during the performance of various laboratory tests in this study.
REFERENCES


