# THE STRENGTH PROPERTIES OF GEOTEXTILES IN OCEAN ENVIRONMENTS

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ABSTRACT: The test program included an outdoor UV exposure program, an exposure test program that placed the samples in a tidal zone, and an immersion program by placing the samples in seawater. A black Polypropylene and a write Polyester geotextiles were used in the study. The test program extended for 12 months. The degradation properties of the geotextiles were evaluated using strip tensile, grab tensile, trapezoidal tear, and puncture tests according to ASTM D5035, D4632, D4533, and D4833 standard test methods. The test results indicated that Ultraviolet exposure was the most significant factor in reducing the strength properties of the test geotextiles. The strength properties of the test specimens decreased as the UV exposure increased. The reduction rate decreased significantly after the first month of exposure. However, the strengths of the test geotextiles immersed in seawater and placed in tidal zone showed minor influence due to UV exposure. Because the polypropylene geotextile contains 2% carbon black and 1% anti-oxidation additives, its strength reduction factors were significantly less than those for the write polyester fabric. The 12-month reduction factors for the polypropylene and polyester geotextiles under grab and strip tensile test methods ranged from 1.01 to 1.31 and 2.59 to 4.06, respectively. The reduction factor associated with the trapezoidal tear test was higher than other test methods. Its values ranged from 1.01 to 1.76, and 1.08 to 5.81 for PP and PEP, respectively. The reduction factors for puncture resistance ranged from 1.00 to 1.64.

## 1 INTRODUCTION

A geotextile is a permeable geosynthetic comprised solely of textiles. They are indeed textiles in the traditional sense, but consist of synthetic fibers rather than natural fibers such as cotton, wool, or silk. These synthetic fibers are made into flexible, porous fabrics using standard weaving machinery or matted together in a random or non-woven manner. Some are also knitted. The vast majority of geotextiles are made from polypropylene (PP) or polyester (PET) fibers or yarns. The major point is that they are porous to liquid flow across their manufactured planes and within their thickness, but to widely varying degrees. Geotextiles are commonly used with foundations, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system. They are at least 100 specific applications for geotextiles. However, the fabric always performs at least one of five discrete functions: separation, reinforcement, filtration, drainage and containment. Geotextile use has experienced growth equaled by any other system in civil engineering and heavy construction. Geotextile sales are projected to grow at 5 to 10% per year.

At present, the professional groups most strongly influenced by Geosynthetics are geotechnical engineering, transportation engineering, environmental engineering and hydraulics engineering. Moreover, geotextiles are widely used in coastline structures and harbor construction. For example, placing geotextiles underneath riprap along a coastline or harbor caisson to prevent soil erosion from these structures. Geotextiles could be immersed in the ocean, placed in tidal zones, or exposed to sunlight. Because the design-life of these structures are typically at least 25 years, the endurance and degradation properties of geotextiles under ocean environments is an important issue for these applications. These properties are closely related to the amount UV exposure and the composition of the seawater.

All of these applications require design procedures that are based on the tensile strength, tear strength and puncture resistance of geotextiles. Generally, grab tensile (ASTM D4632), strip tensile (ASTM D5035), trapezoid tear (ASTM D4533), and index puncture (ASTM D4833) test methods are used to evaluate the engineering properties of geotextiles in the laboratory. Such laboratory-measured engineering properties are not the allowable values for use in the final design. The design value must be suitably reduced to reflect the anticipated in-situ behavior, such as installation damage, long term creep, chemical degradation, ultraviolet degradation, environmental degradation, etc.

### 1.1 *Seawater Chemistry*

Seawater is a solution of salts of nearly constant composition, dissolved in variable amounts of water. There are more than 70 elements dissolved in seawater but only 6 make up 99% of all the dissolved salts. All occur as ions, such as: Chloride (55.0 wt%), Sodium (30.6 wt%), Sulphate (7.7 wt%), Magnesium (3.7 wt%), calcium (1.2 wt%), and Potassium (1.1 wt%).

As well as major elements, there are many trace elements in seawater - e.g., manganese (Mn), lead (Pb), gold (Au), iron (Fe), iodine (I). Most occur in parts per million (ppm) or parts per billion (ppb) concentrations. They are important to some biochemical reactions - both from positive and negative (toxicity) viewpoints.

Oceanographers use salinity -- the amount (in grams) of total dissolved salts present in 1 kilogram of water -- to express the salt content of seawater. Normal seawater has a salinity of 35 grams/kilogram (or liter) of water -- also expressed as 35‰.

Seawater also contains small amounts of dissolved gases (nitrogen, oxygen, carbon dioxide, hydrogen, and trace gases). Water at a given temperature and salinity is saturated with gas when the amount of gas entering the water equals the amount leaving during the same time.

In general, nitrogen and rare inert gases (argon, helium, etc.) behave this way. Their concentrations are conservative and are only affected by physical processes. In contrast, some dissolved gases are non-conservative and actively participate in chemical and biological processes that change their concentrations. Examples are oxygen and carbon dioxide -- released and used at various rates in the oceans, especially by organisms.

### 1.2 *Solar Energy*

As suggested by Coleman and Weicksel (1959), Hsuan etc. (1994) and shown in Figure 1, the incident energy from sunlight is divided into three regions: infrared (about 760 nm and to the right of the chart), visible light (from 760 nm to 400 nm), and UV (below 400 nm). The UV range may be further subdivided into three categories: UV-A (400 nm to 315 nm), which causes some damage to polymers; UV-B (315 nm to 280 nm), which produces the most sever polymer damage; and UV-C (280 nm to 100 nm), which would be extremely damaging to polymers but is found only in outer space. The energy associated with UV range sunlight is only about 5% of the total sunlight energy received on the earth.

Photo-initiated degradation is well known to occur in polymer materials that are exposed to sunlight (Hsuan & Koerner 1993, and Koerner etc. 1994). The initiator for photo-initiated reactions involves energy from sunlight, which initiates a chemical reaction within the polymer. Like other chemical reactions, the rate of degradation is proportional to the availability of the chemical species, the initiation mechanisms and the type and intensity of energy allowing for reaction propagation.

Knowing the degradation mechanism in various types of polymers allows for listing the polymer activation spectra, including those used to make geosynthetic materials. Hirt and Searle (1964) suggested that the activation spectra for Polyethylene = 300 nm; polypropylene = 310 nm and 370 nm; polystyrene = 319 nm; polyvinyl chloride = 320 nm; and polyester = 325 nm. Some of these values are superimposed on the abscissa in Figure 1 for illustration purposes.

Polymer exposure to direct sunlight can be a major source of degradation. The situation is more complicated, however, because moisture, environmental effects and other site-specific phenomena are known to effect degradation rates. During any type of construction that involves geotextiles, the potential for sunlight exposure will exist. The susceptibility of geotextiles to ultraviolet degradation is an important issue if the geotextiles are exposed to sunlight for a long time. Thus, the sunlight stability of geotextiles should be evaluated.

In an ideal situation, the evaluation should be performed at the project site where the geotextiles will be used. Artificial exposure tests or outdoor exposure tests at one location may not be applicable to a project site at another location. The ASTM D5970 (1996) standard test method, Deterioration of Geotextiles from Outdoor Exposure, can be used to evaluate the deterioration of geosynthetic products under site-specific atmospheric conditions over an 18-months period.

The durability of geosynthetics exposed to outdoor UV exposure has been investigated by different researchers (Brand & Pang 1990, McGown etc. 1995, and Cassady & Bright 1995, Hsieh & Lin 2003). The half-life of 12 tested geotextiles ranges from three months to over nine months under Hong Kong outdoor exposure conditions (Brand & Pang 1990). Very small changes in the strength properties of the test PP and HDPE geogrids occurred under the influence of UV radiation and heat cycling in Kuwait (McGown etc. 1995). However, the test results show that the deterioration of exposed geotextiles can be significant and the index test data do not closely reflect the long-term load-strain behavior of geotextiles (McGown etc. 1995). In addition, a minimum additive package concentration was established to preserve the long-term mechanical properties. Carbon black, at 2.5% by weight, is the most effective means for retarding the deteriorating effects of UV light (Cassady & Bright 1995). The tensile strength of test geogrids decreased as the outdoor exposure increased. The rate of tensile strength decrease also decreased as UV exposure was increased. Carbon black and antioxidants contained in the coating materials have a significant influence on the rate of degradation for tested geogrids. Two percent carbon black and 1% antioxidant by weight are recommended (Hsieh & Lin 2003).

This paper focuses on providing a database of geotextile degradation properties in ocean environments. An outdoor UV exposure test program was performed at the Harbor and Marine Technology Research Center, Wuchi, Taichung, Taiwan. A black Polypropylene and a write Polyester geotextiles were used in this study. The test program was started on June 18, 2002, and extended for 12 months. The degradation properties of the geotextiles were evaluated using grab tensile, strip tensile, trapezoidal tear, and puncture tests according to ASTM D4632, D5035, D4533, and D4833 standard test methods. A comparison of the strength properties before and after various UV exposure and seawater weathering were performed. The reduction factors due to UV exposure and seawater weathering for the test geotextiles were also evaluated.

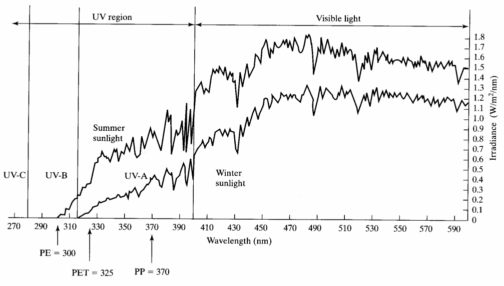


Figure 1 Wavelength spectrum of solar radiation (Coleman and Weicksel 1959)

## 2 TEST MATERIALS

Black polypropylene and write polyester geotextiles, provided by two local manufactures, were used in this study. The manufacture design nominal strengths for the tested PP and PET geotextiles were 70 kN/m and 150 kN/m, respectively. The black PP geotextile was woven from siltfilm fibers, 2% carbon black and 1% antioxidants were mixed in the PP base resin to produce the PP fibers. The white PET geotextile was produced from multifilament fibers. The polyester yarns were all manufactured in Taiwan. The carboxyl end group (CEG) values and molecular weights of the PET yarns were proven by the manufacturers to be less than 30 and greater than 25,000 g/m, respectively.

### 2.1 *Test Data for Unexposed Samples*

To understand the general properties of the tested geotextiles, a series of grab tensile, strip tensile, trapezoidal tear, and puncture resistance tests were performed on these two geotextiles without any UV and weathering exposure. The test samples were wrapped in a black plastic bag and stored in a dark storage room before testing. The average ultimate tensile strength and elongation at break for the test geotextiles at the beginning of the test program (0 month) are summarized in Table 1. The average breaking strengths of the un-weathered geotextiles at different test periods, 0-month to 12-months, are presented in Table 2.

Based upon the test results, the breaking strengths of the test samples throughout the test period are mostly varied within one standard deviation of the data shown in Table 1. The average test results for 0-month were used as the reference data for the following analyses.

Figure 2 Exposure of geotextile samples at the top of the building of the Harbor and Marine Technology Research Center, Wuchi, Taichung, Taiwan

## 3 TEST PROGRAM

The test program included an outdoor UV exposure program according to the ASTM D5970 test standard, an exposure test program involved placing the samples in a tidal zone, and an immersion program by placing the samples in seawater. The weathering test program was performed in the Harbor and Marine Technology Research Center, Wuchi, Taichung, Taiwan. The UV exposure test samples were placed at the top of the Research Center building, as shown in Figure 2. The immersion and tidal zone weathering programs were performed in the Circulation Basin of the Research Center as also shown in Figures 3 and 4. As shown in the figures, the samples were exposed to sunlight or immersed in seawater as the water table changed with the tide for the tidal zone conditions. The samples were placed in stainless steel cages and immersed in seawater with minimum UV exposure for the immersion condition. The seawater in the basin was circulated through pumps according to the tide at the No. 29 Berth of the Taichung Harbor. The seasonal water analyses data for the seawater in the harbor at No. 29 Berth is summarized in Table 3 (RCHMT 1992). The variation in the chemical properties for the seawater was minimal. The test program was started on June 18, 2002, and extended for 12 months. The exact location for this test was longitude of 120$^o$31$^,$ East and latitude of 24$^o$15$^,$ North at a sea elevation of 3 meters. The test periods were 0-month, 1-month, 2-months, 4-months, 8-months, and 12-months. The average monthly weather data obtained from the Taichung Harbor weather station, such as, temperature, humidity, rainfall and sunlight duration, are summarized in Table 4. The accumulated monthly UVA and UVB energies obtained from the weather stations near the test site (Changhua station and Taichung station) within 30 kilometers are summarized in the Table 5. The average monthly temperatures for the winter are about 10$^o$c lower than those for the summer. The monthly humidity is about the same for the all year round. The accumulated monthly UVA and UVB for the winter are only 50% and 60% of the values for the summer, respectively.

## 4 TEST RESULTS AND DISCUSSIONS

The degradation properties of the geotextiles were evaluated using grab tensile, strip tensile, trapezoidal tear, and puncture tests according to ASTM D4632, D5035, D4533, and D4833 standard test methods. The average test value for the 0-month un-weathered sample was used as the reference data in the following comparison studies.

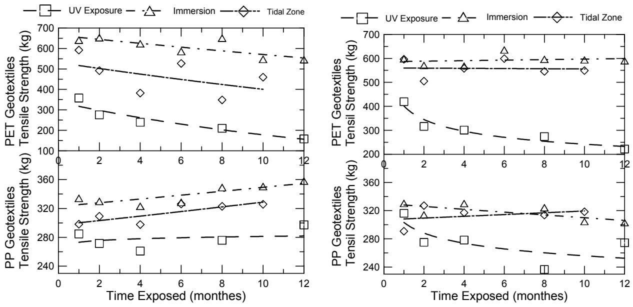
The variations in the average grab tensile strength and elongation at break for the polypropylene and polyester geotextiles under various weathering conditions during the test period are shown in Figure 5. The data for the strip tensile, trapezoidal tear, and puncture test methods are summarized in Figures 6, 7, and 8. In general shown in the figures, the ultimate tensile strength and elongation at break decreased as the outdoor weathering time increased. The rate of decrease in tensile strength and elongation was more significant for the samples under UV exposure conditions, especially in the early stages (June, and July) of the test program. Relatively, the effect of weathering on tensile strength was least significant for the seawater immersion weathering condition. The weathering effect for the tidal zone condition was slightly higher than that for the immersion condition. However, the effect of weathering on elongation at break for tidal zone and immersion conditions is not clear. Based upon the information shown above, the effect of UV exposure on the engineering properties on the tested geotextiles was much more significant than the chemical degradation effect due to seawater weathering.

As for the weathering effect on the engineering properties of test geotextiles evaluated by various test methods, the reduction in tear strength due to the weathering program is more significant than the other test methods. However, the reduction in puncture resistance was much lower than the other test methods.

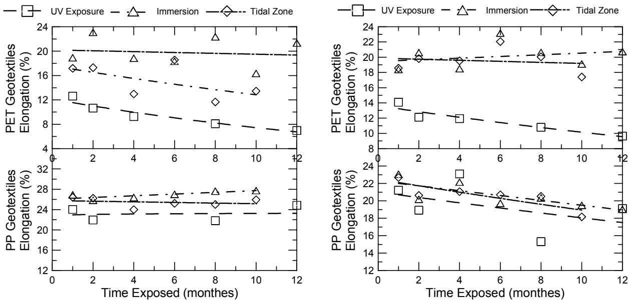
By comparing the test data associated with the PP and PET geotextiles under different weathering conditions, the amount and rate of reduction for the strength and elongation at break were all more significant for the data associated with PET geotextiles. This should be related to the additives within the polypropylene fibers. As mentioned earlier, the polypropylene fibers contained 2% carbon black and 1% antioxidants. It seems that those compounds significantly reduced the degradation of polypropylene fibers under UV exposure and seawater immersion. In addition, since no enough carboxyl end group information for the polyester fiber, the PET fiber hydrolysis reaction within seawater could also reduce the long-term durability of PET geotextiles.

Figure 3 Exposure of geotextile samples in the tidal zone of the Circulation Basin of the Harbor and Marine Technology Research Center, Wuchi, Taichung, Taiwan

Figure 4 Immerse of geotextile samples in the Circulation Basin of the Harbor and Marine Technology Research Center, Wuchi, Taichung, Taiwan

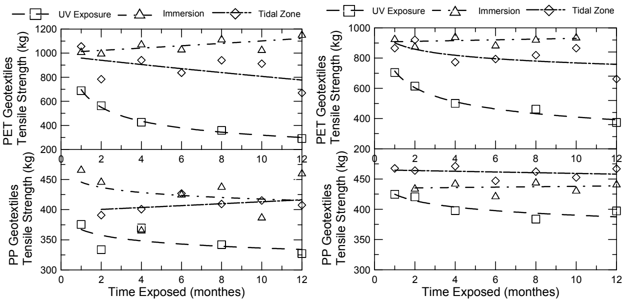


(a) Tensile strength of MD (b) Tensile strength of XD

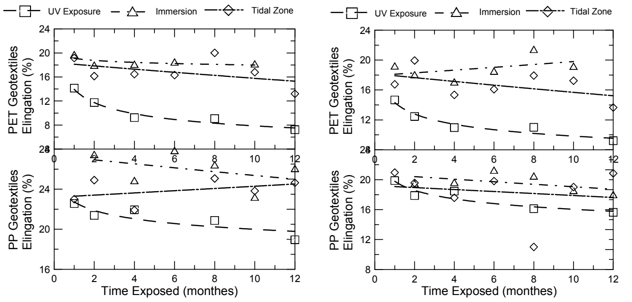


(c) Elongation at break of MD (d) Elongation at break of XD

Figure 5 The variation of the average grab tensile strengths and elongations at break for the geotextiles under various weathering conditions during the test period

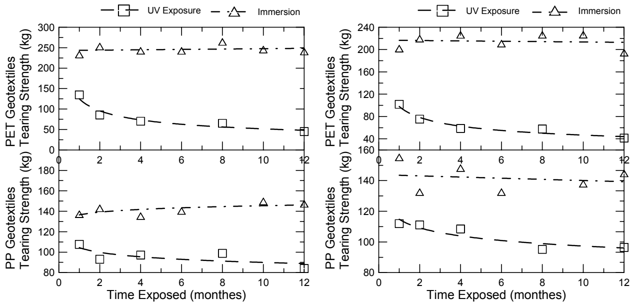


(a) Tensile strength of MD (b) Tensile strength of XD



(c) Elongation at break of MD (d) Elongation at break of XD

Figure 6 The variation of the average strip tensile strengths and elongations at break for the geotextiles under various weathering conditions during the test period



(a) Trapezoidal trars of MD (b) Trapezoidal trars of XD

Figure 7 The variation of the average trapezoidal tears and elongations at break for the geotextiles under various weathering conditions during the test period

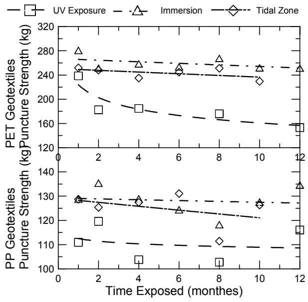


Figure 8 The variation of the average puncture resistance for the geotextiles under various weathering conditions during the test period

As mentioned earlier, the design value must be suitably reduced by various reduction factors to reflect the anticipated in-situ behavior. The reduction factor can be obtained by inverting the un-weathered reference data for different properties. The reduction factors for the test geotextiles for different engineering properties under various weathering conditions at 12-month weathering period are summarized in Table 6. The reduction factors associated with UV exposure weathering condition were greater than those for the other two conditions. The reduction factors for the polyester geotextile were generally greater than those for PP geotextiles. The reduction factors for puncture resistance were relatively lower in comparing with the other test methods. The reduction factors for tear strength were much higher than the other test methods. The values varied from 1.01 to 5.81. However, the general reduction factors for the grab tensile and strip tensile strength for 12 months UV exposure were about 1.08, 1.19, and 2.95, 3.45 for polypropylene and polyester geotextiles, respectively.

## 5 SUMMARY AND CONCLUSIONS

The objective of this study was to investigate the degradation properties of two types of geotextiles in Ocean Environments. The weathering test program included an outdoor UV exposure program according to the ASTM D5970 test standard, an exposure test program that placed the samples in a tidal zone, and an immersion program that placed samples in seawater. The test program was performed at the Harbor and Marine Technology Research Center, Wuchi, Taichung, Taiwan. A black Polypropylene and a white Polyester geotextiles were used in this study. The test program was started on June 18, 2002, and extended for 12 months. The retrieved samples were sent back to the laboratory for testing. The samples were cleaned and chemical residual removed according to ASTM D543 standard procedures before proceeding further property evaluation test. The degradation properties of the geotextiles were evaluated using strip tensile, grab tensile, trapezoidal tear, and puncture tests according to ASTM D5035, D4632, D4533, and D4833 standard test methods. The following conclusions are based on the test results:

The annual (2002-2003) UVA and UVB exposure energies at the test site (central region of Taiwan) were 279.14 MJ/m$^2$ and 1.14 MJ/m$^2$, respectively. The annual rainfall was 1301 mm and the annual number of bright sunshine-hours was 2427.3 hours for the outdoor test site.

UV exposure presents a significant source for geotextile degradation. The ultimate tensile strength and elongation at break decreased as the outdoor weathering time increased. However, the rate of deterioration in tensile strength and elongation at break was not directly proportional to the UV exposure energy.

Seawater immersion had less weathering effect on the engineering properties of the test geotextiles among the test conditions. The effect of placing samples within the tidal zone on engineering properties was slightly higher than that for the immersion condition. However, the weathering effect on elongation at break for the tidal zone and immersion conditions was not significant.

The effect of weathering on the reduction in tear strength was more significant than other test methods. The weathering effect on the reduction in puncture resistance was much lower than that for the other test methods.

The weathering effect on the polypropylene geotextile engineering properties was much less than that associated with the polyester geotextile. This could be related to the polypropylene resin containing 2% carbon black and 1% antioxidants for producing the fibers.

The reduction factors associated with the UV exposure weathering condition were greater than those for the other two conditions. The reduction factors for the polyester geotextile were generally greater than those for the PP geotextiles. The reduction factors for puncture resistance were relatively low compared with the other test methods. The reduction factors for tear strength under UV exposure were much higher than that for the other test methods. The values varied from 1.64 to 5.81. However, the general reduction factors for the grab tensile and strip tensile strength for UV exposure of 12-months were about 1.08, 1.19, and 2.95, 3.45 for polypropylene and polyester geotextiles, respectively.

## 6 ACKNOWLEDGEMENTS

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Table 1 Summary of the engineering properties for un-weathered test geotextiles at the beginning of the test program

| Item | Type | Direction | Strength(kg) | | Elongation(%) | | Number of Specimens |
|---|---|---|---|---|---|---|---|
| | | | Average | Standard Deviation | Average | Standard Deviation | |
| Grab Tensile | PP-B | MD | 300.63 | 28.13 | 25.67 | 3.03 | 10 |
| | | XD | 319.28 | 9.03 | 21.74 | 1.92 | 10 |
| | PET-W | MD | 523.22 | 24.40 | 18.57 | 1.89 | 10 |
| | | XD | 573.96 | 14.41 | 23.15 | 1.02 | 10 |
| Strip Tensile | PP-B | MD | 428.33 | 20.28 | 27.06 | 0.86 | 5 |
| | | XD | 426.82 | 18.59 | 20.01 | 1.16 | 8 |
| | PET-W | MD | 1182.44 | 15.44 | 24.85 | 1.47 | 5 |
| | | XD | 1056.31 | 49.67 | 20.91 | 0.64 | 8 |
| Trapezoid Tearing | PP-B | MD | 148.13 | 12.62 | -- | -- | 10 |
| | | XD | 157.84 | 17.08 | -- | -- | 10 |
| | PET-W | MD | 260.99 | 14.52 | -- | -- | 10 |
| | | XD | 234.72 | 13.75 | -- | -- | 10 |
| Puncture | PP-B | -- | 127.69 | 11.68 | -- | -- | 15 |
| | PET-W | -- | 251.73 | 19.84 | -- | -- | 15 |

Table 2 Summary of the average breaking strengths for the un-weathered geotextile samples for different test methods with various exposure periods

| Month | Type | Grab Tensile (kg) | | Strip Tensile (kg) | | Trapezoid Tearing (kg) | | Puncture(kg) |
|---|---|---|---|---|---|---|---|---|
| | | MD | XD | MD | XD | MD | XD | -- |
| 0 | PP | 300.63 | 319.28 | 428.33 | 426.82 | 148.13 | 157.84 | 127.69 |
| | PET | 523.22 | 573.96 | 1182.44 | 1056.31 | 260.99 | 234.72 | 251.73 |
| 1 | PP | 324.73 | 310.32 | 449.98 | 445.23 | 156.46 | 181.19 | 112.87 |
| | PET | 556.24 | 570.30 | 1011.34 | 1047.94 | 279.30 | 226.38 | 251.80 |
| 2 | PP | 308.42 | 314.44 | 439.36 | 456.81 | 146.70 | 166.10 | 131.75 |
| | PET | 601.57 | 626.67 | 1008.01 | 1018.32 | 268.21 | 226.85 | 241.15 |
| 4 | PP | 303.80 | 334.36 | 398.00 | 458.91 | 161.64 | 150.42 | 125.67 |
| | PET | 538.87 | 539.40 | 1146.93 | 1025.89 | 251.59 | 222.39 | 243.37 |
| 6 | PP | 334.07 | 310.36 | 418.42 | 458.91 | 159.53 | 161.16 | 122.71 |
| | PET | 530.56 | 508.67 | 1131.01 | 1055.30 | 268.30 | 225.26 | 240.90 |
| 8 | PP | 313.89 | 271.59 | 421.93 | 422.44 | 141.61 | 145.67 | 116.70 |
| | PET | 493.34 | 504.63 | 1107.85 | 1000.95 | 264.65 | 228.66 | 241.12 |
| 10 | PP | 350.41 | 312.36 | 421.620 | 431.716 | 126.47 | 120.88 | 131.87 |
| | PET | 534.81 | 523.65 | 1019.84 | 982.73 | 255.59 | 231.69 | 236.48 |
| 12 | PP | 338.09 | 291.21 | 383.678 | 456.461 | 127.22 | 119.58 | 129.28 |
| | PET | 529.22 | 510.34 | 1138.27 | 982.84 | 251.63 | 227.42 | 240.89 |

Table 3 Summary of the seasonal water analysis data for the seawater obtained from No. 29 Berth, Taichung Harbor, Taiwan

| Month | Salinity (ppt) | Electricity Conductivity (mS/cm) | Electricity Resistance (Ω/cm) | Oxygen Content (mg/ℓ) | PH Value | Temperature (□) | Cl$^-$ Content (ppm) |
|---|---|---|---|---|---|---|---|
| 2 | 34.4 | 47.6 | 21.0 | 7.6 | 8.46 | 23.7 | 19023 |
| 5 | 33.7 | 51.8 | 19.3 | 5.1 | 7.89 | 29.9 | 18153 |
| 8 | 34.0 | 51.6 | 19.4 | 7.6 | 8.09 | 26.5 | 19267 |
| 11 | 34.7 | 52.6 | 19.0 | 7.7 | 8.18 | 24.3 | 19899 |

Table 4 Summary of the monthly weather data for the test period obtained from Taichung Harbor Weather Station (Central Weather Bureau, Taiwan)

| Month | Temp. (℃) | Humidity (%) | Rainfalls (mm) | Sunshine Hours (hrs.) |
|---|---|---|---|---|
| Jun. 2002 | 28.9 | 79 | 30 | 190.4 |
| Jul. 2002 | 29.1 | 78 | 265 | 227.7 |
| Aug. 2002 | 29.0 | 79 | 314.5 | 222.8 |
| Sep. 2002 | 27.3 | 78 | 116 | 211.2 |
| Oct. 2002 | 25.1 | 75 | 28 | 193.3 |
| Nov. 2002 | 21.1 | 68 | 6.5 | 180.4 |
| Dec.2002 | 18.5 | 78 | 94 | 158.7 |
| Jan. 2003 | 15.5 | 75 | 29.5 | 199.3 |
| Feb.2003 | 17.8 | 81 | 37.5 | 162.2 |
| Mar.2003 | 18.7 | 79 | 19.5 | 156.5 |
| Apr. 2003 | 23.5 | 84 | 137.5 | 131.7 |
| May 2003 | 25.8 | 78 | 73 | 195.5 |
| Jun. 2003 | 27.2 | 81 | 150 | 197.6 |

Table 5 Summary of monthly accumulated UV energy for the nearby Weather Stations of the test site (Central Weather Bureau, Taiwan)

| Month | Changhua Station UVA (MJ/m$^2$/Day) | Taichung Station UVB (MJ/m$^2$/Day) |
|---|---|---|
| 1 | 31.63 | 0.12 |
| 2 | 31.86 | 0.12 |
| 3 | 29.75 | 0.12 |
| 4 | 26.32 | 0.10 |
| 5 | 22.49 | 0.08 |
| 6 | 17.88 | 0.06 |
| 7 | 17.48 | 0.06 |
| 8 | 19.20 | 0.07 |
| 9 | 11.61 | 0.09 |
| 10 | 11.62 | 0.08 |
| 11 | 30.64* | 0.12 |
| 12 | 28.66* | 0.12 |

Note: UVA data were missed due to equipment damaged; average monthly data were used to fill the missed data.

Table 6 Summary of the reduction factors of the test geotextiles for different engineering properties under various weathering conditions after 12-months weathering period

| Geotextiles | Condition | Grab Tensile | | Strip Tensile | | Trapezoid Tearing | | Puncture |
|---|---|---|---|---|---|---|---|---|
| | | MD | XD | MD | XD | MD | XD | -- |
| PP | UV Exposure | 1.01 | 1.16 | 1.31 | 1.07 | 1.76 | 1.64 | 1.10 |
| | Seawater Immersion | 0.84 | 1.05 | 0.93 | 0.96 | 1.01 | 1.09 | 0.95 |
| | Tide Zone | *0.92 | *1.00 | 1.05 | 0.91 | N.A. | N.A. | *1.01 |
| PET | UV Exposure | 3.32 | 2.59 | 4.06 | 2.83 | 5.81 | 5.70 | 1.64 |
| | Seawater Immersion | 0.96 | 0.97 | 1.02 | 0.98 | 1.08 | 1.21 | 1.00 |
| | Tide Zone | *1.14 | *1.05 | 1.77 | 1.60 | N.A. | N.A. | *1.10 |

Note: * indicates 10-months data is used.

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