Statistical Analysis of the Influence of Temperature and Humidity on the Stability of Geomembrane Mechanical Test

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Abstract. Using mathematical statistics, we analyzed the influence of temperature and relative humidity during test on the results. The test data of geomembrane were obtained by changing the temperature and relative humidity ranging from 18\degree C to 25\degree C and from 50\% to 70\% respectively. The results show that under different temperature and humidity, the coefficient of variation of the maximum tensile test value is 8.0\%–17.4\%, and the coefficient of variation of average value is 6.7\%, which is poor in stability; the coefficient of variation of the test value of elongation at break is 4.7\% ~ 11.7\%, and the coefficient of variation of average value is 4.6\%, and the value increases with increasing temperature; the coefficient of variation of right angle tear strength is 6.0\% ~ 20.7\%, and the coefficient of variation of average value is 6.4\%; the coefficient of variation of puncture strength test value is 4.2\% ~ 7.3\%, and the coefficient of variation of average value is 6.1\%, and the value decreases with the increase of temperature. These results will shed light on analyzing the influence of temperature and humidity on the mechanical test results of geomembrane and determining a reasonable temperature and humidity control range for geomembrane testing.

1. Introduction

The raw materials of geomembrane mainly include high-density polyethylene, linear low-density polyethylene, polypropylene, polyvinyl chloride, high flexibility and toughness polyethylene and ethylene propylene diene monomer \cite{1}. These polymer materials have low melting point and strong temperature sensitivity \cite{2,3}, which shows that the linear expansion coefficient of geomembrane is large. When the external environment temperature drops, the geomembrane will shrink and increase its elastic modulus and tensile strength \cite{4,5}. If the geomembrane cannot deform freely, it will produce temperature stress \cite{6-8}, which will affect the performance of geomembrane. When testing geomembrane, the temperature and humidity of the test environment should be controlled within a certain range. The purpose of this study is to analyze the influence of temperature and humidity on the mechanical test results.

2. Material and methods

The test material was linear low-density polyethylene (LLDPE) geomembrane mixed with 5\% double resistant carbon black master batch. Tensile test, right angle tear test and puncture test were carried out.
Considering the range of general indoor temperature and humidity, the temperature of 18℃, 21℃ and 25℃ and the relative humidity of 30%, 50% and 70% were selected to form nine different temperature and humidity conditions. The sample was adjusted for 24h to make it fully deformed to stable under the set temperature and humidity, and then the test samples were prepared. The temperature and humidity in the test room were consistent with those during the conditioning.

The influence of temperature and humidity on the results is manifested as changes in numerical values and discrete characteristics. Therefore, arithmetic average, standard deviation (SD), coefficient of variation (CV) and relative deviation (RSD) of extreme value were selected to analyze the test data and their average values under different temperature and humidity.

3. Results and analysis

3.1. Tensile test

3.1.1. Maximum tension. The tensile test was carried out on type 5 specimens with a width of 6mm, and the maximum tensile force occurred during tensile fracture. Statistical analysis results of maximum tension are shown in Table 1. At different temperature and humidity, the standard deviations, coefficients of variation and extreme value relative deviations of test value are large, with obvious dispersion and variability, and wide data distribution. The stability of the test value is poor, and the trend of data stability with temperature and humidity is not obvious. The dispersion of the average value of the maximum tensile force under different temperature and humidity is obviously weakened, but it still has a certain degree of dispersion and distribution width. It can be seen from Figure 1 that the change trend of the maximum tensile force with temperature and humidity in the range of 18℃ ~ 25℃ and 30% ~ 70% is not obvious.

Table 1. Statistical analysis results of maximum tension.

| Temp and RH | Avg (N) | SD (N) | CV (%) | RSD of Min (%) | RSD of Max (%) |
|------------|--------|-------|--------|----------------|---------------|
| 18℃,30%    | 26.8   | 3.53  | 13.2   | -28.0          | 13.4          |
| 18℃,50%    | 29.4   | 5.12  | 17.4   | -33.3          | 20.7          |
| 18℃,70%    | 31.5   | 2.90  | 9.2    | -16.2          | 11.7          |
| 21℃,30%    | 30.1   | 4.56  | 15.1   | -28.6          | 18.6          |
| 21℃,50%    | 30.8   | 3.89  | 12.6   | -26.3          | 15.9          |
| 21℃,70%    | 27.0   | 3.85  | 14.3   | -18.9          | 22.6          |
| 25℃,30%    | 27.1   | 3.14  | 11.6   | -11.8          | 27.7          |
| 25℃,50%    | 26.4   | 4.01  | 15.2   | -29.2          | 25.0          |
| 25℃,70%    | 27.9   | 2.23  | 8.0    | -12.2          | 9.3           |
| Avg under different Temp and RH | 28.6 | 1.92 | 6.7 | -7.7 | 10.1 |

Figure 1. Maximum tension of geomembrane.
Due to the long tensile time, the small maximum tensile force and the small sample width of geomembrane, the test results are easily affected by the sample level. In addition, the thickness of the geomembrane is small, and the uneven thickness has a greater impact on the results. Therefore, changing the temperature and humidity in the range of 18°C~25°C and 30%~70%, the key factors affecting the dispersion, average level and central tendency of the maximum tensile force data are still the sample preparation level and the uniformity of the material.

3.1.2. Elongation at break. Statistical analysis results of elongation at break are shown in Table 2. It can be seen from Table 4 that the breaking elongation of the geomembrane is very large, and the coefficients of variation of the test value range from 4.7% to 11.7%. At the temperature and humidity of (18°C, 50%) and (21°C, 70%), the test values have certain dispersion and variability. Compared with the maximum tensile force, the elongation at break has better data stability. Same as the maximum tensile force, the discrete characteristics of elongation at break data do not change significantly with temperature and humidity. The key factors affecting the discrete characteristics are still sample preparation level and material uniformity.

The coefficient of variation of the average value of the elongation at break of the geomembrane is 4.6%, and the relative deviations of the minimum and maximum values are -5.9% and 8.2%, respectively. Compared with the test value, the dispersion and distribution width are significantly reduced, with a better central tendency and weaker variability. The relationship between elongation at break and temperature and humidity is shown in Figure 2. With the increase of temperature, the elongation at break of geomembrane increases, because the higher temperature can make the geomembrane have better deformation capacity.

| Temp and RH | Avg (%) | SD (%) | CV (%) | RSD of Min (%) | RSD of Max (%) |
|-------------|---------|--------|--------|----------------|----------------|
| 18°C,30%    | 763.5   | 52.0   | 6.8    | -8.1           | 11.9           |
| 18°C,50%    | 750.7   | 68.6   | 9.1    | -17.1          | 10.1           |
| 18°C,70%    | 795.8   | 37.4   | 4.7    | -6.0           | 8.1            |
| 21°C,30%    | 781.6   | 54.4   | 7.0    | -12.3          | 7.1            |
| 21°C,50%    | 812.7   | 46.6   | 5.7    | -7.7           | 13.4           |
| 21°C,70%    | 765.3   | 89.7   | 11.7   | -20.9          | 17.6           |
| 25°C,30%    | 827.3   | 54.5   | 6.6    | -11.4          | 7.3            |
| 25°C,50%    | 819.0   | 54.7   | 6.7    | -16.6          | 6.9            |
| 25°C,70%    | 863.3   | 48.6   | 5.6    | -13.4          | 5.5            |
| Avg under different Temp and RH | 797.7  | 36.3   | 4.6    | -5.9           | 8.2            |

Figure 2. Elongation at break of geomembrane.
3.2. Right angle tear
Statistical analysis results of right-angle tearing force are shown in Table 3. The right-angle tearing force of geomembrane is small, and the test results are greatly affected by the sample level. The smoothness, angle and thickness of the right-angle position have obvious influence on the test results, which leads to some instability. The relationship between right angle tearing force and temperature and humidity is shown in Figure 3. It can be seen from Table 3 and Figure 3 that the dispersion and distribution width of right-angle tearing force test values is larger when the temperature and relative humidity is (25\(^{\circ}\)C, 30%), and the dispersion characteristics and data distribution width at other temperature and humidity are relatively close. The coefficient of variation of right-angle tearing force increases with the increase of temperature.

| Temp and RH | Avg (N) | SD (N) | CV (%) | RSD of Min (%) | RSD of Max (%) |
|-------------|---------|--------|--------|----------------|----------------|
| 18\(^{\circ}\)C,30% | 20.1 | 1.3 | 6.5 | -9.5 | 10.0 |
| 18\(^{\circ}\)C,50% | 18.7 | 1.3 | 7.0 | -10.7 | 8.0 |
| 18\(^{\circ}\)C,70% | 19.9 | 1.2 | 6.0 | -7.0 | 12.1 |
| 21\(^{\circ}\)C,30% | 22.8 | 1.7 | 7.5 | -10.5 | 7.9 |
| 21\(^{\circ}\)C,50% | 19.7 | 1.3 | 6.6 | -8.1 | 12.2 |
| 21\(^{\circ}\)C,70% | 21.3 | 1.4 | 6.6 | -8.5 | 7.0 |
| 25\(^{\circ}\)C,30% | 21.3 | 4.4 | 20.7 | -18.8 | 32.9 |
| 25\(^{\circ}\)C,50% | 18.7 | 1.4 | 7.5 | -12.3 | 9.6 |
| 25\(^{\circ}\)C,70% | 20.0 | 2.0 | 10.0 | -9.5 | 19.5 |
| Avg under different Temp and RH | 20.3 | 1.3 | 6.4 | -7.9 | 12.3 |

Figure 3. Variation coefficient of right-angle tearing force.

Figure 4. Right angle tearing force of geomembrane.

The coefficient of variation of the average value of the right-angle tearing force at different temperature and humidity is 6.4\%, and the relative deviations of the minimum value and maximum value are -7.9\% and 12.3\%, indicating that the test value of the right-angle tearing force has a certain variability and distribution width. The relationship between right angle tearing force and temperature and humidity is shown in Figure 4. At the same temperature, the right-angle tearing force is the largest when the relative humidity is 30\%; at the same relative humidity, the right-angle tearing force is the largest when the temperature is 21\(^{\circ}\)C.

The right-angle tear strength is the right-angle tearing force per unit thickness, which considers the change of thickness with temperature and humidity. Statistical analysis results of the right-angle tear strength are shown in Table 4. The coefficients of variation of right-angle tear strength at different temperatures and humidities range from 3.0\% to 11.9\%. The coefficient of variation of the average value of right-angle tear strength is 5.6\%, and the relative deviations of the minimum value and
The maximum value are -8.5% and 6.7%, respectively. The variability and data distribution width of the right-angle tear strength are smaller than that of the right-angle tearing force, but the trend of dispersion and concentration with temperature and humidity are more complicated.

### Table 4. Statistical analysis of right-angle tear strength.

| Temp and RH  | Avg (kN/m) | SD (kN/m) | CV (%) | RSD of Min (%) | RSD of Max (%) |
|--------------|------------|-----------|--------|----------------|----------------|
| 18°C, 30%    | 141.0      | 9.3       | 6.6    | -9.4           | 8.1            |
| 18°C, 50%    | 136.0      | 7.6       | 5.6    | -11.2          | 6.7            |
| 18°C, 70%    | 131.6      | 15.7      | 11.9   | -8.5           | 25.5           |
| 21°C, 30%    | 149.1      | 10.5      | 7.0    | -7.7           | 13.7           |
| 21°C, 50%    | 147.8      | 6.5       | 4.4    | -6.9           | 4.1            |
| 21°C, 70%    | 151.9      | 14.7      | 9.7    | -11.5          | 18.2           |
| 25°C, 30%    | 153.4      | 13.3      | 8.7    | -9.5           | 13.9           |
| 25°C, 50%    | 135.5      | 4.0       | 3.0    | -4.6           | 4.5            |
| 25°C, 70%    | 148.2      | 8.1       | 5.5    | -6.1           | 8.2            |
| Avg under different Temp and RH| 143.8 | 8.0 | 5.6 | -8.5 | 6.7 |

### 3.3. Puncture

Statistical analysis results of piercing force are shown in Table 5. The results show that the dispersion and variation degree of penetration force test values at different temperature and humidity are small, the data distribution width is not large, and coefficient of variation and relative deviation of extreme values do not change significantly with temperature and humidity, that is, the influence of temperature and humidity on the data dispersion is not obvious.

The coefficient of variation of the average value of piercing force at different temperatures and humidity is 6.1%, the piercing force value is the smallest at the temperature and relative humidity of (25°C, 50%), and the relative deviation of the minimum value is -14.0%. The average value of piercing force at different temperature and humidity still has a certain dispersion and distribution width.

Figure 5 shows the relationship between the piercing force and temperature and humidity. It can be seen from Figure 5 that the piercing force of the geomembrane decreases with the increase of temperature. At 18°C and 21°C, the piercing force values of geomembrane with different relative humidity are very close, and the influence of relative humidity on them increases at 25°C.

### Table 5. Statistical analysis of piercing force.

| Temp and RH  | Avg (N) | SD (N) | CV (%) | RSD of Min (%) | RSD of Max (%) |
|--------------|---------|--------|--------|----------------|----------------|
| 18°C, 30%    | 85.4    | 6.1    | 7.1    | -6.3           | 10.7           |
| 18°C, 50%    | 86.3    | 3.6    | 4.2    | -6.4           | 6.0            |
| 18°C, 70%    | 84.9    | 5.6    | 6.6    | -7.8           | 13.2           |
| 21°C, 30%    | 82.0    | 5.6    | 6.8    | -9.5           | 9.3            |
| 21°C, 50%    | 81.7    | 4.6    | 5.6    | -5.4           | 8.8            |
| 21°C, 70%    | 83.6    | 3.8    | 4.5    | -6.5           | 5.7            |
| 25°C, 30%    | 77.9    | 4.3    | 5.5    | -7.4           | 7.4            |
| 25°C, 50%    | 70.0    | 4.8    | 6.9    | -8.9           | 11.1           |
| 25°C, 70%    | 80.8    | 5.9    | 7.3    | -8.3           | 11.1           |
| Avg under different Temp and RH| 81.4 | 5.0 | 6.1 | -14.0 | 6.0 |
4. Conclusions

(1) The maximum tensile force of geomembrane tensile test has obvious instability, which is greatly affected by sample level and material uniformity, and is not significantly affected by changes of temperature and humidity. The data stability of elongation at break is better than the maximum tensile force, and the elongation at break increases with the increase of temperature.

(2) The stability of the geomembrane right angle tear test is easily affected by the sample level. When the temperature is $21^\circ C$ at the same relative humidity and 30% RH at the same temperature, the right-angle tearing force is larger.

(3) The puncture test has good stability. The temperature and humidity have no obvious influence on the data dispersion. The average value of piercing force of the geomembrane decreases with the increase of temperature.

References

[1] Cai, Q. (2009) Experimental Study on Tensile Force in the Geomembrane Due to Compaction Work and Temperature Variation. Zhejiang University of Technology, Hangzhou.

[2] Schmachtenberg, E., Schoeche, N. (1999) Advances in calculating thermally induced stresses in nonlinear viscoelastic materials. Polymer Engineering and Science, 39(4): 767–777.

[3] He, D., Mei, F. (2013) Effect of polyethylene materials on properties of high density polyethylene geomembrane. Plastics Science and Technology, 41(6): 53–56.

[4] Merah, N., Saghir, F., Khan, Z., et al. (2006) Effect of temperature on the tensile properties of HDPE pipe material. Plastics, Rubber, Composites, 35: 226–230.

[5] Fang, C., Xu, S., Yang, Y., et al. (2010) Study on temperature stress of HDPE geomembrane. China Building Waterproofing, (6):10–12.

[6] Aya, T., Nakayama, T. (1997) Influence of environmental temperature on yield stress of polymers. JSME International Journal (Series A), 40(3): 343–348.

[7] Imaizumi, S., Kawamata, K., Tsuboi, M. (1999) Study on thermal stress within the geomembrane liner induced by temperature decrease. In: Proceedings of the 7th International Landfill Symposium, pp.115–122.

[8] Xu, S., Yang, Y., Hong, B. (2006) Evaluation of temperature stress and stress relaxation properties of HDPE sheet. Journal of Southeast University (Natural Science Edition), 36(5): 820–824.