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Prediction of the Service Life of Composite Geomembrane Based on Hygrothermal Aging Test

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Abstract – *By studying the mechanical property of 150g/m2-0.3mm-150g/m2 composite geomembrane under four kinds of temperature and humidity conditions, the variation of tensile strength and elongation of the composite geomembrane with aging time is analyzed. Based on the Arrhenius thermal aging accelerated model, the tensile strength is reduced to 20% of the initial performance as a failure criterion. The hygrothermal accelerated aging prediction model of composite geomembrane is established, and the service life of the composite geomembrane in natural environment is predicted.*

Keywords – chygrothermal aging test, composite geomembrane, failure criterion, tensile strength, service life.

1. INTRODUCTION

As a kind of geosynthetics, composite geomembrane is a kind of polymer chemical flexible material composed of plastic film as anti-seepage base material and nonwoven fabrics, which has been widely used in large water conservancy projects and other engineering fields due to its small specific gravity, strong extensibility and high adaptability to deformability and other features [1]-[8]. Its main mechanism is to isolate the water leakage passage with the impermeable property of plastic film, withstand the water pressure and adapt to the deformation of building with its greater tensile strength and elongation. Therefore, the safe operation of the project is closely related to the performance of composite geomembrane.

In natural environment, composite geomembrane will be aged by the influence of environmental factors, such as ultraviolet radiation, temperature, humidity, chemical mediators, thus greatly affecting the internal structure and mechanical properties of materials. When its performance falls to a certain extent, it will inevitably affect the normal operation of the project, so it is one of the most reliable methods to evaluate its service life by the attenuation law of mechanical properties [9]-[12].

However, the life prediction of composite geomembrane is relatively difficult because of its short application time in the field of geotechnical engineering [13], [14]. Usually, the life prediction of composite materials is based on accelerated aging test of laboratory. The service life of geosynthetics is determined by the relationship between time and temperature [15]-[18]. In this paper, based on the indoor accelerated hygrothermal aging test, the hygrothermal accelerated aging model was established with the tensile strength decreased to 20 percent of the initial performance as the failure criterion and the Arrhenius thermal aging model as the foundation, so as to determine its service life in natural environment.

2. TEST

2.1 Test Material

The composite geomembrane used in Hebi, Henan partial canal sections of the South to North Water Transfer Project is chosen as the test material, and its specification is $150g/m^2$-0.3mm-$150g/m^2$ with two cloth plus one film. The cloth is the polyester filament needled geotextile with wide width (the width is greater than 5m), and the film is the polyethylene film. According to the *"Polythene geomembrane"* (GB/T17643-2011), *"Geosynthetics"* (GB/T17639-2008, GB/T17642-2008) and the features of the South to North Water Transfer Project, the technical performance index of the composite geomembrane meets the requirements in Table 1.

2.2 Test Method and Condition

The test method of accelerated aging is adopted in the test, and the design of aging test scheme is shown in Table 2.

2.3 Test Process

The CMT4104 microcomputer controlled electronic universal testing machine was used in the test to determine the tensile strength and the corresponding elongation of the strip sample. According to the requirement of the regulation SL235-2012, the tensile rate was set as 20mm/min, and the initial distance between the two fixtures was adjusted to 100mm. The sample was clamped in the fixtures, and then open the

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test machine and start the recording device at the same time to record the tension and elongation curve until the sample was destroyed.

Table 1. Performance index requirements of composite geomembrane.

Name \ Index	Film thickness	Density	Tensile stress	Elongation	Modulus of elasticity at 5 degrees centigrade	Frost resistance (brittle temperature)	Associative strength	Tear strength	Impermeability	Permeability coefficient
Polyethylene film	≥0.3mm	> 920kg/m^3	> 17MPa	> 450%	> 70MPa	≥-70 ℃	> Strength of base metal	> 60kN	No seepage with water pressure of 1.05MPa	< 10^{-11}cm/s
Name \ Index	Thickness	Elongation	Tensile strength	CBR bursting strength	Tear strength	Peel strength	Hydrostatic pressure	Vertical permeability coefficient	—	—
Composite Geomembrane (complex)	≥2.7mm	> 50%	≥14kN/m	≥2.8kN	≥0.4kN	≥6N/cm	≥0.6MPa	< 10^{-11}cm/s	—	—

Table 2. Design and aging test scheme.

Test type	Test instrumental for hygrothermal aging	Test temperature and humidity	Test indicators	Related index test equipment
Hygrothermal aging	LT-BIX200HLM Type high and low temperature test chamber	40°C, RH95% 60°C, RH85% 60°C, RH95%	Mass	TG 628A electronic balance
			Thickness	YG (B) 141D digital fabric thickness meter
			Tensile strength and elongation	CMT4104 electronic universal testing machine

Table 3. Results of hygrothermal aging accelerated test.

Test temperature and humidity	Cycle/d	Tensile strength/kN/m	Elongation/%
40°C, 95%	0	22.080	76.460
	30	21.150	74.880
	60	21.040	73.320
	80	19.735	71.180
	100	18.675	71.275
	120	18.310	70.910
	131	17.840	68.160
	145	17.850	68.030
60°C, 85%	0	22.080	76.460
	10	21.890	73.990
	40	20.560	68.350
	55	19.990	67.330
	64	19.810	66.580
	72	19.660	65.625
	80	19.275	63.520
	87	19.360	62.340
	94	18.900	61.640
60°C, 95%	0	22.080	76.460
	11	21.170	72.970
	18	21.020	70.485
	26	20.590	69.430
	40	19.330	66.840

3. TEST RESULTS AND ANALYSIS

The prepared samples with different specifications were put into LT-BIX200HLM type high and low temperature test chamber, which were respectively conducted with hygrothermal aging tests under different temperature and humidity. The samples were removed at set intervals to be conducted with measurement and test of related physical properties and mechanical properties, and the results are shown in Table 3, among which, the relationship curves between tensile strength, elongation and aging time are shown in Figure1 and Figure 2.

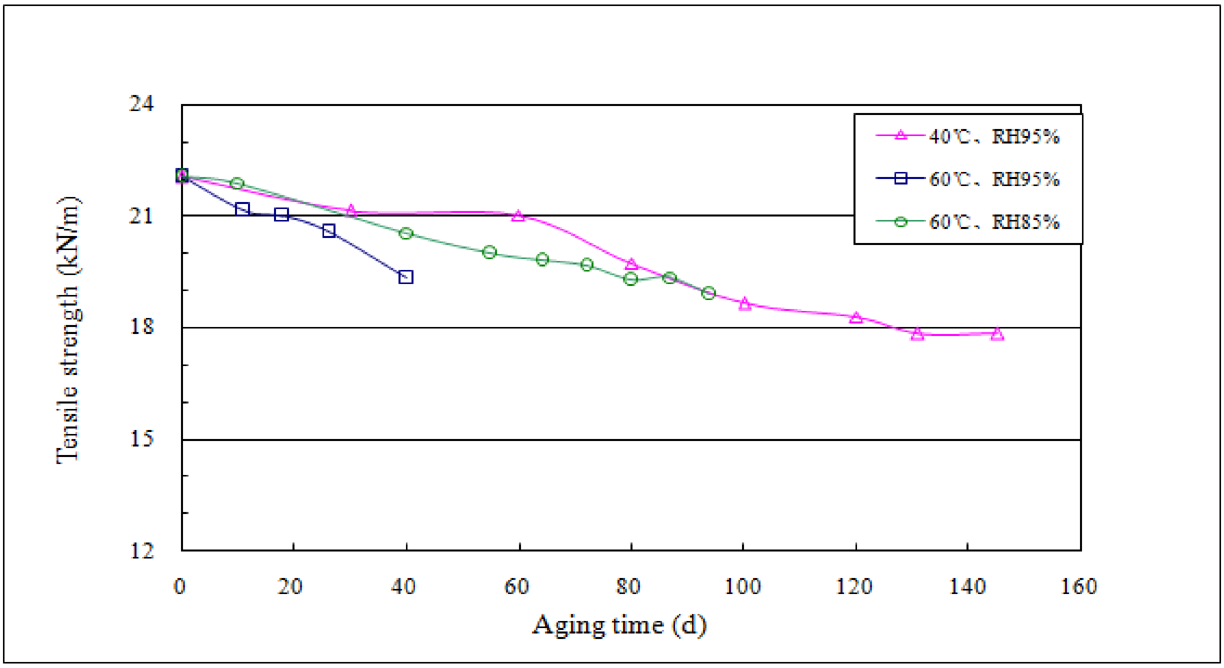

Fig. 1. Curves of relationship between tensile strength and aging time.

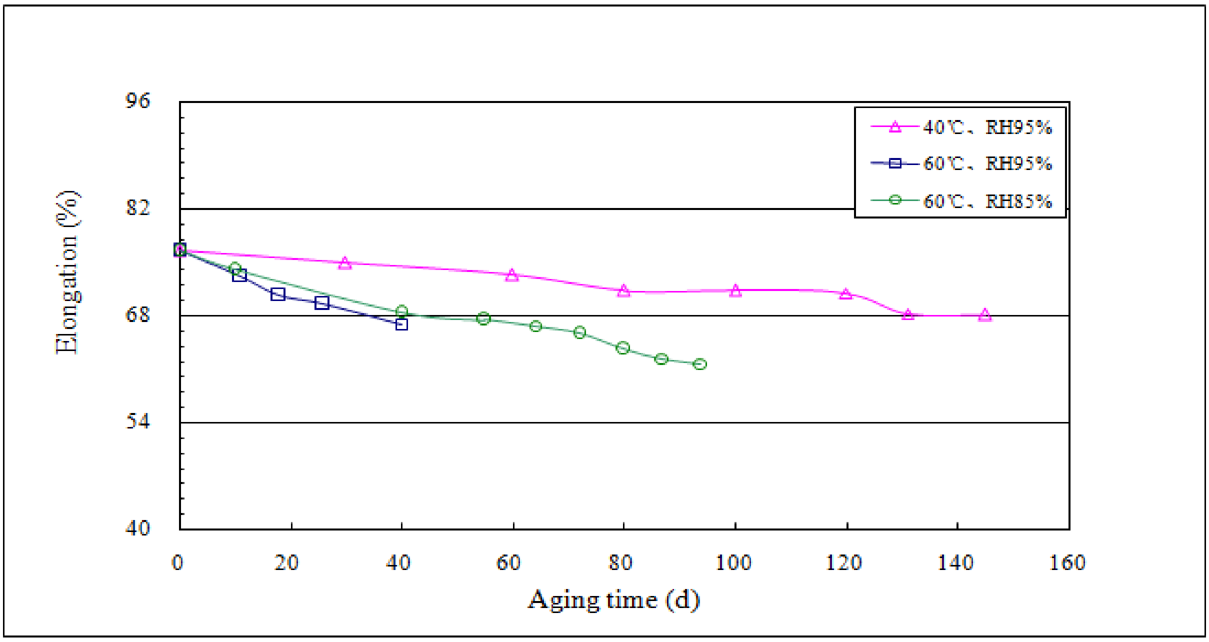

Fig. 2. Curves of relationship between elongation and aging time.

As shown in Table 3, the tensile strength and elongation of the composite geomembrane show the overall decline trend with the increase of aging time; the decreasing rate of the tensile strength and elongation of the composite geomembrane is significant with the change of test temperature and humidity. The decreasing rates are different under the three different test conditions with the performances that the higher the temperature is, the greater the humidity is, the faster the decreasing rate is, the faster the attenuation of mechanical properties is; the lower the temperature is, the smaller the humidity is, the lower the decreasing rate is, the lower the attenuation of mechanical properties is. The tensile strength and elongation decrease most greatly with the temperature of 60°C, and the humidity of 95%. The decreasing rate of tensile strength and elongation is in the middle with the temperature of 60°C and the humidity of 85%; the tensile strength and elongation decrease slowly with the temperature of 40°C and the humidity of 95%.

4. DETERMINATION OF ACCELERATED MODEL AND LIFE PREDICTION

The composite geomembrane in the South to North Water Transfer Project is used as anti-seepage material, whose main mechanism is to isolate the water leakage passage with the impermeable property of plastic film, withstand the water pressure and adapt to the deformation of the building with its greater tensile strength and elongation. Therefore, the change of tensile strength index is used in this paper to predict the service life of composite geomembrane.

4.1 Determination of Hygrothermal Aging Accelerated Model

4.1.1 Hygrothermal Aging Accelerated Model

According to the results of test analysis of Figure 1 and Table 3, the exponential curve is selected as the regression model of the tensile strength of the composite geomembrane with the change of aging time. That is:

$$P = P_0 e^{-kt} \tag{1}$$

Where: P is the tensile strength of composite geomembrane after the aging time of t, *kN/m*; P_0 is the initial tensile strength of composite geomembrane, *kN/m*; k is the aging rate associated with temperature and humidity; t is the aging time, *d*.

4.1.2 Determination of Hygrothermal Aging Rate

Based on the Arrhenius thermal aging accelerated model, the influence of humidity on aging rate is considered in this paper, thus obtaining the aging rate model under the joint action of temperature and humidity.

$$k = \frac{a}{T} e^{\frac{B}{T}} e^{bH} \tag{2}$$

Where: k is the aging rate associated with temperature and humidity; a, b and B are the undetermined constants; T is the thermodynamic temperature, K; H is the humidity, %.

In the above formula, there is a nonlinear relationship between variables, so linear regression is carried out to the upper formula through variable transformation, as shown in formula (3).

$$\ln kT = \ln a + \frac{B}{T} + bH \tag{3}$$

According to the regression analysis of formula (3) based on test data, the fitting results are shown in Table 4, and the obtained aging rate model under the joint action of temperature and humidity is shown in formula (4).

$$k = \frac{439.0781}{T} e^{\frac{-4109.6462}{T}} e^{6.614H} \tag{4}$$

Table 4. Regression analysis results of aging rate to temperature and humidity.

T/K	*k*	*H*	ln*a*	*B*	*b*
333.15	0.0016	0.85			
313.15	0.0015	0.95	6.0847	-4109.6462	6.6140
333.15	0.0031	0.95			

Table 5. Life prediction result of composite geomembrane with consideration of temperature and humidity.

Temperature condition, °C	Humidity condition, %	Corresponding aging rate	Failure criterion	Service life/year
14.1 °C	60	4.9E-5	0.2 P_0	89.1

4.1.3 Determination of Life Predication Model

The formula (4) of aging rate model is substituted to the formula (1) to obtain the change rule of tensile strength of composite geomembrane with the aging time under the joint action of temperature and humidity. That is:

$$P = P_0 e^{-\frac{439.0781t}{T} e^{\frac{-4109.6462}{T}} e^{6.614H}} \tag{5}$$

Where: P is the tensile strength of composite geomembrane after the aging time of t, *kN/m*; P_0 is the initial tensile strength of composite geomembrane, *kN/m*; T is the thermodynamic temperature, K; t is the aging time; H is the humidity, %.

4.2 Life Prediction

The average annual temperature of the selected canal section is 14.1°C. Considering the influence of humidity, assume that the selected canal sections is operated under the temperature of 14.1°C and humidity of 60% all the year round with the tensile strength decreased to 20% of the initial performance as the failure criterion, so as to predict the service life of composite geomembrane, and then the temperature of 14.1°C and humidity of 60% are substituted to the formula (5) to obtain that the service life of composite geomembrane under this condition is 89.1 years, as shown in Table 5.

5. CONCLUSIONS

1) The results of hygrothermal aging test of composite geomembrane show that the tensile strength, elongation and tear strength show the overall decline trend with the increase of aging time; the decreasing rates are different with the change of test temperature and humidity. The higher the temperature is, the greater the humidity is, the faster the decreasing rate is, the faster the attenuation of

mechanical properties is; the lower the temperature is, the smaller the humidity is, the lower the decreasing rate is, the lower the attenuation of mechanical properties is.

2) Based on the thermal aging accelerated test model of composite geomembrane, the life prediction model of composite geomembrane under the hygrothermal aging condition is established with the tensile strength decreased to 20% of initial performance as the failure criterion to predict the service life of composite geomembrane, thus obtaining that the service life of composite geomembrane under this condition is 89.1 years with the temperature of 14.1°C and humidity of 60%.
3) The test results of composite geomembrane performance have large discreteness due to the production technology and its own defects, such as the uneven thickness and soon, thus there may be some effects on the accuracy of life prediction.
4) There is no mature test method and standard of composite geomembrane hygrothermal aging test for reference. Therefore, the research on life prediction of composite geomembrane by this method is still in exploration stage, which needs further improvement in future research.

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