ISSN 1027-5495. Functional Materials, 28, No.2 (2021), p. 353-358.
doi:https://doi.org/10.15407/fm28.02.353

The tensile strength attenuation law of compound geomembrane materials with hygrothermal aging experiment

***Yi He*[1], *Xiaomin Jia*[1], *Min Zhang*[2]**

[1]Civil Engineering Department, Luoyang Institute of Science and Technology, Henan, 471023 Luoyang, China
[2]Yellow River Institute of Hydraulic Research, Henan, 450003 Zhengzhou, China

Received December 26, 2020

The rule of change in tensile strength depending on the exposure time during hygrothermal aging is obtained. Based on the Arrhenius thermal aging model, a model was created to predict the weakening of the tensile strength of a complex geomembrane due to hygrothermal aging, when the value of the longitudinal tensile strength decreased to fifty percent of the initial value. The results show that the discrepancy between the predicted tensile strength model and the value obtained in practice under similar conditions is 8.19 %.
Keywords: compound geomembrane, hygrothermal ageing experiment, tensile strength, failure criterion.

Закон загасання міцності на розрив складних геомембранних матеріалів в експерименті з гігротермальним старінням. *Yi He, Xiaomin Jia, Min Zhang*
Отримано правило зміни міцності на розрив після гігротермічного старіння в залежності від часу. На основі моделі термічного старіння, коли значення поздовжньої міцності на розрив зменшилося до п’ятидесяти відсотків від початкового значення, була створено модель прогнозування ослаблення міцності на розрив складної геомембрани за рахунок гігротермального старіння. Результати показують, що розбіжність між результатом прогнозу моделі міцності на розтягнення і значенням, отриманим на практиці при аналогічних умовах, становить 8,1 %.

Получено правило изменения прочности на разрыв после гигротермического старения в зависимости от времени. На основе модели термического старения, когда значение продольной прочности на разрыв уменьшилось до пятидесяти процентов от начального значения, создана модель прогнозирования ослабления прочности на разрыв сложной геомембраны за счет гидротермального старения. Результаты показывают, что расхождение между результатом прогноза модели прочности на растяжение и значением, полученным на практике при аналогичных условиях, составляет 8,19 %.

1. Introduction

Composite geomembrane is a kind of geosynthetic polymer chemical flexible material composed of non-woven fabric and plastic film which is an impermeable substrate [1]. Its main purpose is to block the water leakage channel due to the impermeability of the plastic membrane and withstand water pressure, as well as to adapt to the building deformation through greater tensile strength and elongation [2].

In the natural environment, the composite geomembrane will be aging under influence of environmental factors such as ultraviolet radiation, temperature, humidity and chemical media, which will have a great im-

Table 1. Composite geomembrane properties

Name	Indexes							
	Thickness	Elongation	Tensile strength	CBR bursting strength	Tearing strength	Peel strength	Hydrostatic pressure resistance	Vertical permeability coefficient
Composite geomembrane	≥2.7 mm	>50 %	≥14 kN/m	≥2.8 kN	≥0.4 kN	≥6 N/cm	≥0.6 MPa	$<10^{-11}$ cm/s

Table 2. The scheme design of aging experiment

Test type	Hygrothermal aging Tester	Test temperature and humidity	Test indexes	Related index test equipment
Hygrothermal aging	LT-BIX200HLM high and low temperature test chamber	40°C, RH95 % 60°C, RH85 % 60°C, RH95 % 60°C, RH100 %	Mass	TG628A electronic balance
			Thickness	YG(B)141D digital fabric thickness gauge
			Longitudinal tensile strength and elongation; transverse tensile strength and elongation	CMT4104 electronic universal testing machine

pact on the internal structure and mechanical properties of the material. When its performance drops to a certain extent, it will inevitably affect the normal operation of the facility. At present, for the indoor aging test research of composite geomembrane materials, the effects of ultraviolet rays and temperature are mainly considered. The composite geomembrane material as an impermeable substrate is usually placed in the dam or channel, that is, the upper part of the composite geomembrane material is covered with a protective layer, therefore, the influence of ultraviolet radiation on the material aging is very limited. The mechanical properties of composite geomembrane materials are most influenced by the complex effects of temperature and humidity. Modeling the prediction of aging is one of the most reliable methods for 4 assessing its service life, taking into account the law of attenuation of mechanical properties [3–5]. A hot and difficult point in the problem of aging of composite geomembrane materials is the modeling of a real engineering environment for the use of materials; carrying out indoor tests to accelerate hygrothermal aging of composite geomembrane materials; creation of a model for predicting the law of tensile strength decay of composite geomembrane materials under the combined effect of temperature and humidity to determine the service life of materials in the natural environment. In this research, for the indoor tests to accelerate hygrothermal aging of composite geomembrane materials, the longitudinal tensile strength reduced to 50 % of the initial performance was taken as the failure criterion [5]; the Arrhenius model of thermal aging acceleration was used as the basis; a model was created to predict the law of decay of tensile strength of composite geomembrane materials under the combined effect of temperature and humidity in order to determine the service life of materials in the natural environment and provide a technical guarantee of safe and efficient operation of water supply systems.

2. Experimental

The composite geomembrane was 600 g/m^2 (150 g/m^2–0.3 mm–150 g/m^2) (two geotextiles and one membrane) material; geotextile is a wide fabric (width > 5 m), stitched with a polyester thread needle, and the membrane is a polyethylene membrane. The technical performance indexes of composite geomembrane materials are shown in Table 1.

This project adopts the indoor hygrothermal accelerated aging experimental method, and the aging experimental scheme design is shown in Table 2.

The samples of different specifications were put into a LT-BIX200HLM high and low temperature test chamber; the hygrothermal aging tests were carried out under different temperature and humidity conditions, and the samples were taken out

Table 3. Test results of hygrothermal aging experiment

Test temperature and humidity	Cycle, d	Longitudinal tensile strength, kN/m	Longitudinal elongation, %	Longitudinal modulus of elasticity, MPa	Transverse tensile strength, kN/m	Transverse elongation, %	Transverse modulus of elasticity, MPa	Longitudinal tearing strength, kN	Transverse tearing strength, kN
40°C, 95 %	0	22.080	76.460	33.534	16.370	85.000	25.394	0.730	0.630
	30	21.150	74.880	32.730	15.270	81.690	32.528	0.696	0.623
	60	21.040	73.320	30.010	14.380	77.730	30.631	0.670	0.610
	80	19.735	71.180	35.134	13.780	77.330	28.829	0.669	0.586
	100	18.675	71.275	31.714	13.580	76.940	32.641	0.668	0.579
	120	18.310	70.910	40.934	13.585	74.600	30.892	0.634	0.570
	131	17.840	68.160	36.511	13.380	72.855	34.350	0.585	0.567
	145	17.850	68.030	36.735	13.620	71.705	36.800	0.514	0.564
60°C, 95 %	0	22.080	76.460	33.534	16.370	85.000	25.394	0.730	0.630
	11	21.170	72.970	25.061	15.170	82.270	30.176	0.695	0.612
	18	21.020	70.485	32.028	14.920	79.090	32.317	0.681	0.602
	26	20.590	69.430	27.685	15.030	76.375	36.526	0.662	0.581
	40	19.330	66.840	24.060	13.975	73.195	22.988	0.602	0.561
60°C, 85 %	0	22.080	76.460	33.534	16.370	85.000	25.394	0.730	0.630
	10	21.890	73.990	27.795	16.190	82.300	5.614	0.700	0.613
	40	20.560	68.350	30.241	16.050	79.660	5.560	0.669	0.601
	55	19.990	67.330	21.228	15.937	76.680	34.037	0.657	0.589
	64	19.810	66.580	45.552	15.800	75.480	36.552	0.650	0.577
	72	19.660	65.625	35.376	16.370	74.397	5.582	0.637	0.558
	80	19.275	63.520	48.021	15.650	73.720	36.849	0.617	0.544
	87	19.360	62.340	42.652	15.373	72.000	33.276	0.601	0.521
	94	18.900	61.640	39.171	15.160	69.960	25.777	0.585	0.520
	87	16.535	67.520	40.838	15.373	72.000	33.276	0.633	0.521
	94	15.830	63.530	45.576	15.160	69.960	25.777	0.675	0.572
60°C, 100 %	0	22.080	76.460	33.534	16.370	85.000	25.394	0.730	0.630
	10	20.810	68.670	32.843	16.190	82.300	5.614	0.725	0.623
	40	19.710	67.810	52.026	16.050	81.660	5.560	0.698	0.551
	55	18.360	67.540	38.245	15.937	77.680	34.037	0.628	0.528
	64	18.287	67.460	41.603	15.800	77.480	36.552	0.633	0.614
	72	17.820	66.020	48.278	16.370	77.397	5.582	0.657	0.558
	80	17.070	63.970	39.899	15.650	70.720	36.849	0.617	0.544
	87	16.535	67.520	40.838	15.373	72.000	33.276	0.633	0.521
	94	15.830	63.530	45.576	15.160	69.960	25.777	0.675	0.572

at intervals. (The aging rate of composite geomembrane materials under different temperature and humidity conditions is not the same, so the sampling time interval is different. The sampling time interval is short when the test temperature and humidity are high, and long when the test temperature and humidity are low). Electronic balance, thickness gauge, electronic universal testing machine and other instruments were used to measure and test the physical and mechanical properties of the samples [6].

3. Results and discussion

The test results are shown in Table 3. As can be seen from Table 3, the longitudinal and transverse tensile strength, elongation and tearing strength of the composite geomembrane materials decrease with an increase in the aging time, and the decline rate of mechanical properties is different under different temperature and humidity conditions. For three different test conditions, the higher the temperature and the higher the humidity, the faster the attenuation of mechanical properties; the lower the temperature and the lower the humid-

Table 4. Aging rate of the composite geomembrane at the same temperature and different humidity

Test temperature and humidity	Fitting curve	Aging rate k	Correlation index R
60°C, 85 %	$P = 22.08e^{-0.0016t}$	0.0016	0.9929
60°C, 95 %	$P = 22.08e^{-0.0031t}$	0.0031	0.9839
60°C, 100 %	$P = 22.08e^{-0.0033t}$	0.0033	0.9862

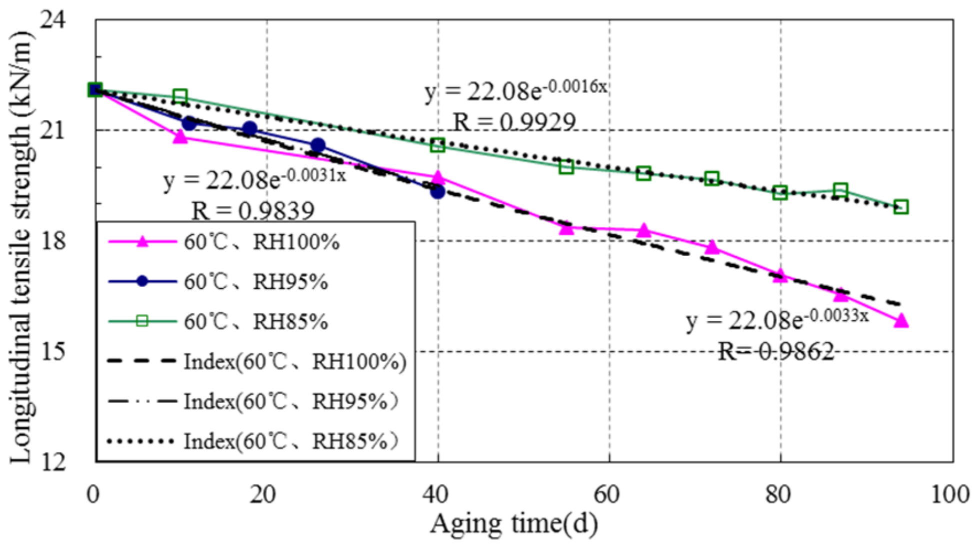

Fig. Curves fitting plot of relationship between tensile strength and aging time of composite geomembrane at the same temperature and different humidity.

ity, the slower the attenuation of mechanical properties. When the temperature is 60°C and the humidity is 95 %, the decrease rate of the tensile strength and elongation is the fastest; when the temperature is 40°C and the humidity is 95 %, the decrease rate of the tensile strength and elongation is the slowest.

3.1 Identification and verification of the model

3.1.1. The hygrothermal aging acceleration model [7–9]

According to the test results in Table 3, the exponential curve is selected as the regression model for the change of the tensile strength of composite geomembranes with aging time. That is:

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

In the formula: P is the tensile strength of the composite geomembrane after aging for time t, kN/m; P_0 is the initial tensile strength of the composite geomembrane, kN/m; k is the aging rate related to temperature and humidity; t is the aging time (days).

3.1.2. Determination of hygrothermal aging rate

a) The aging rate under different humidity conditions

Considering the influence of humidity on the aging rate, the relationship curve between the tensile strength and aging time under the same temperature and different humidity is fitted, as shown in Figure, and the aging rate of the composite geomembrane under the same temperature and different humidity is obtained, as shown in Table 4.

b) The relationship between the aging rate and humidity.

According to the analysis results, the relationship between the aging rate and humidity of the composite geomembrane under the same temperature and different humidity conditions is determined as an exponential function:

$$k = ae^{hH}. \tag{2}$$

In the formula, k is the aging rate of composite geomembranes, related only to humidity; a and b and undetermined constants; H is the humidity, %.

Table 5. The regression analysis between the aging rate and humidity

Curve type	Expression	Value range	Analysis results	Correlation index
Exponential curve	$k = ae^{hH}$	$0 \le H \le 1$	Adopt	0.9675

Table 6. The regression analysis result of aging rate under the temperature and humidity

T, K	k	H	ln$a$	B	b	Correlation index
333.15	0.0016	0.85				
313.15	0.0015	0.95	6.0847	−4109.6462	6.6140	0.9954
333.15	0.0031	0.95				

c) The aging rate under the combined action of temperature and humidity.

Based on the Arrhenius model of thermal aging acceleration [10–12], considering the influence of humidity on the aging rate, the aging rate formula of composite geomembranes under the combined action of temperature and humidity is expressed as follows:

$$k = \frac{a}{T}e^{B/T}e^{hH}. \quad (3)$$

In the formula, k is the aging rate related to temperature and humidity; a, b and B are undetermined constants; T is the thermodynamic temperature, K; H is the humidity, %.

By regression analysis of formula (3), the aging rate model formula of composite geomembrane materials under the combined action of temperature and humidity can be obtained, as shown in formula (4), that is:

$$k = \frac{439.0781}{T}e^{\frac{-4109.6462}{T}}e^{6.614H}. \quad (4)$$

3.1.3 Modeling the law of tensile strength attenuation during hygrothermal aging

By substituting the aging rate model formula (4) into formula (1), it is possible to obtain a model of the law of changing the tensile strength of composite geomembrane materials with aging time under the combined action of temperature and humidity. That is:

$$P = P_0\frac{e^{-439.0781t}}{T}e^{-\frac{4109.6462}{T}}e^{60614H}. \quad (5)$$

In the formula, P is the tensile strength (kN/m) of the composite geomembrane after aging for time t; P_0 is the initial tensile strength (kN/m) of the composite geomembrane; T is the thermodynamic temperature (K); t is the aging time (days), H is the humidity (%).

4.2 Model validation

Combined with the practical application of composite geomembrane materials, taking into account the comprehensive effect of temperature and humidity, the longitudinal tensile strength of composite geomembrane materials was predicted for 5 years in the Xixiayuan Project. The measured value of the longitudinal tensile strength of the composite geomembrane materials used for 5 years in Xixiayuan Project is basically consistent with the predicted hygrothermal aging tensile strength attenuation according to the model law, and the discrepancy is 8.19 %. The prediction reliability of the model meets the engineering requirements.

4. Conclusions

The rate of a decrease in the longitudinal and transverse tensile strength, elongation and tearing strength of composite geomembrane materials changes significantly with test temperature and humidity. The higher the temperature and humidity, the faster the mechanical properties of materials deteriorate. The lower the temperature and humidity, the slower the attenuation of mechanical properties of materials. Under the same humidity conditions, the higher the temperature, the faster the attenuation of mechanical properties of the composite geomembrane material. At the same temperature, the higher the humidity, the faster the tensile strength, elongation and tearing strength of composite geomembrane materials decrease.

The theory of kinetics of chemical reactions is applied to simulate the law of weakening of the tensile strength of composite geomembrane materials. The tensile strength curve of the materials under different environmental conditions is taken as the dynamic curve. Based on the Arrhenius equation which only considers the effect of temperature, taking into account the influence of humidity on the aging rate of composite geomembrane materials, the aging rate formula is obtained for composite geomembrane materials under the comprehensive effect of temperature and humidity, and for these materials a model of tensile strength weakening under hygrothermal aging test conditions is established.

Combined with the practical application in the Xixiayuan Project, the tensile strength weakening law model of composite geomembrane materials under hygrothermal aging test is verified in practical engineering. After 5 years of operation, the discrepancy between the measured and predicted values of the longitudinal tensile strength of composite geomembrane material is 8.19 %.

References

1. Wang Zhao, Geosynthetics, Beijing, China Machine Press (2005).
2. A.Bouazza, J.Zornberg, D.Adam, Geosynthetics in Waste Containment Facilities: Recent Advances, Geosynthet-ics-7th ICG-Delmas (2002).
3. H.P.Sangam, R.K.Rowe, *Geotext. Geomembr.*, **19**, 329 (2001).
4. R.Kerry Rowe, B.Fady, M.Zahirul, *J. Geotechn. Geoenvironm. Eng.*, **140**, 1 (2015).
5. Y.G.Hsuan, R.M.Koerner, *J. Geotechn. Geoenvironm. Eng. ASCE*, 532 (1998).
6. Standard of Ministry of water resources of the people's Republic of China. Specification for test and measurement of geosynthetics(SL 235-2012). Ministry of water resources of the people's Republic of China (2012).
7. R.K.Rowe, S.Rimal, H.Sangam, *Geotext. Geomembr.*, **27**, 137 (2009).
8. Yu.V.Suvorova,S.I.Alekseeva et al., *J. Mach. Manufact. Reliab.*, **39**, 391 (2010).
9. E.W.Brand, E.R.Pang, *J. Geotechn. Eng.*, **6**, 979 (2011).
10. M.A.Weidong, L.V.Changzhi, L.I.Zhiguo, *Microelectr.*, **41**, 621 (2011).
11. Yanhong Sun, Hong Pi, Shaoyun Guo. *Lifetim. Polymer Mater. Scien. Eng.*, **28**, 133 (2012).
12. Huaiyi Yan, Yingjin Wang, *J. Shaoxing Univ.*, **30**, 12 (2010).
13. Li li., Inspection report of 400 g/m^2/0.8 mm/400 g/m^2 compound geomembrane of Xixiayuan project. Zhengzhou: Engineering inspection Center of Yellow River Institute of Hydraulic Research (2014).