Experimental Study on Long-Term Working Performance of Reinforced Material for Crushed Stone

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Abstract. The long-term performance of the reinforced material is an important factor affecting the safety, stability and economic rationality of the reinforced structure, as well as an important design parameter of the reinforced structure, which is affected by the construction damage, creep, aging and other factors during the construction and use of the reinforced material.In order to determine the long-term strength of reinforcement in the use of gravel reinforced structure, three kinds of reinforcement, HDPE, PET and PEC, were selected to carry out field full-size construction damage test and indoor tensile, creep and durability and other basic characteristics tests, and the following conclusions were obtained: (1) The protective layer of medium coarse sand with a thickness of 5cm can effectively reduce the construction damage of the reinforcement in the crushed stone. (2) The comprehensive reduction coefficients of PET180, HPDE150 and PEC200 without protective layer are about 2.60, 3.47 and 3.15, which can be reduced by about 7.0% after the protective layer is set. (3) The design strength calculated by nominal tensile strength and measured coefficient is safe, and the safety margin is about 1.06. (4) Compared with PET and PEC, the test parameters of strength and elongation of high-density polyethylene HPDE are more stable. The research results can provide a reference for the design of the reinforced material of the gravel reinforced structure.

Keywords: Gravel structure; Reinforcement material; Long-term strength; Construction damage; Creep; aging

1 INTRODUCTION

The reinforced structure takes advantage of the high tensile strength of the reinforcement and adds it to the fill body, and combines the tensile strength of the reinforcement with the compressive strength of the soil through the mutual friction between the reinforcement and the soil, which can limit the lateral deformation of the upper and lower soil and improve the strength and stability of the reinforced structure [1]. However, in the process of engineering practice, engineers are more and more aware that

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there are still many unsolved problems in the design of reinforced soil structure[2-4]. The long-term working performance of the reinforced material is an important parameter in the design of the reinforced structure, which affects the safety, stability and economic rationality of the reinforced structure. However, influenced by numerous human and natural factors, especially creep characteristics, aging and wear of machinery and fillers in the construction process, will seriously weaken the usable strength of the reinforced material [5]. In the gravel-reinforced structure, because the structural reinforcement bears important loads, the creep deformation caused by long-term stress may cause the whole structure deformation, and then affect its stability and safety. With the passage of time, the structural reinforcement may be affected by environmental chemicals, oxidation and other factors and gradually fail, resulting in the reduction of material strength and stiffness. In addition, the damage that may occur during the construction process, such as welding defects, cracks, etc., will also affect the long-term performance of the structural reinforcement. The combined influence of these factors will lead to the gradual reduction of the usable strength of the structural reinforcement material, thus affecting the safety and reliability of the overall structure. The determination of the long-term strength of the reinforcement requires the maximum tensile strength of the reinforcement and the reasonable value of various reduction coefficients in the application process [6].

At present, the domestic standard [6-7] has certain provisions on the value of long-term strength T_a of reinforced material. The ultimate tensile strength T_u is divided by the comprehensive reduction coefficient, and the value of the comprehensive reduction coefficient is given as 2.5~5.0, as shown in formula (1).

$$T_a = \frac{T_u}{RF} = \frac{T_u}{RF_{CR} \cdot RF_{ID} \cdot RF_D} \tag{1}$$

Where: T_u is the measured tensile strength; RF_{CR} is the strength reduction coefficient of the material due to creep. RF_{ID} is the strength reduction factor of the material damaged in the construction process; RF_D is the strength reduction factor affected by long-term aging of materials. RF is the comprehensive strength reduction factor.

Relevant studies have been conducted on various reduction coefficients at home and abroad and different recommended values have been put forward. For example, Li Guangqing et al. [8] studied the influence of the particle size of fill material on the construction reduction coefficient, and believed that the construction reduction coefficient showed an increasing trend with the increase of particle size, and gave the construction damage reduction coefficient of unidirectional tensile grid HDPE 1.05~1.13. Creep reduction coefficient 2.3~2.4, aging reduction coefficient 1.0; Ding Jinhua et al. [9] believe that the critical stress level of creep of HDPE grating under conventional conditions should not be greater than 40%, and the chemical action can lead to an increase of about 10% in the grating creep variable. Hu Hanbing et al. [10] believe that the construction damage coefficient of polyester fiber grille in gravel filler is 1.29~1.36. Ren Jiali et al. [11] believe that the comprehensive reduction coefficient of HDPE grille in gravel filler is about 3.50. The influence of reinforced soil interface and construction damage on creep is very significant [12-14], but the design is inconvenient due to the existence of a large range of value intervals, and there are few relevant studies on the long-term strength of coarse grain reinforcement.

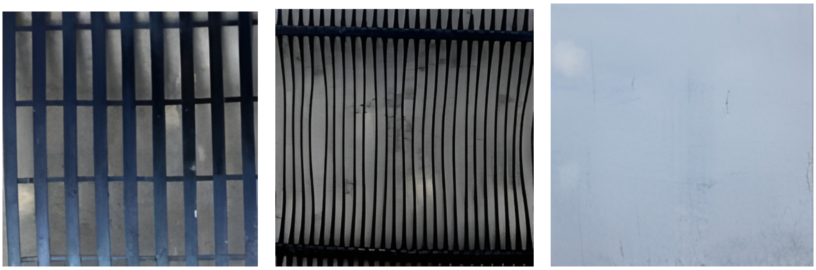
This article aims to address the problems of difficult particle size control and sharp grain edges commonly found in moderately weathered rock blasting materials. Three geotechnical reinforcement materials, namely unidirectional high-density polyethylene (HDPE), high-strength polyester fiber (PET), and high-strength geotextile (PEC), were selected to conduct full-scale tests on the construction damage of reinforcement materials in the field, as well as tests on the basic properties of tensile strength, durability, and creep of reinforcement materials before and after rolling. The tensile strength and deformation characteristics of reinforcement materials in crushed stone reinforced structures under three working conditions, namely with protective layer on top, with protective layer on both top and bottom, and without protective layer, were studied. The reasonable values of reduction factors for construction damage, aging, and creep were obtained. The research results can provide a reference for the design of crushed stone reinforced structures.

2 REINFORCEMENT CONSTRUCTION DAMAGE REDUCTION FACTOR.

2.1 Raw Materials

The filling material shall be excavated by blasting of medium-weathered limestone, with the maximum particle size no more than 15cm and mud content < 7%. It is required to have good grading, non-uniformity coefficient $C_u \geq 5$, curvature coefficient $C_C = 1\sim3$; The protective layer is made of medium coarse sand with mud content < 5% and fineness modulus ≥2.3.

Three kinds of reinforcement materials, PET180 with nominal tensile strength of 180kN/m, HPDE150 with nominal tensile strength of 150kN/m and PEC200 with nominal tensile strength of 200kN/m, were selected for the test. Figure 1 is the physical diagram of the three kinds of reinforcement, and Table 1 is the technical parameters of the reinforcement.



a.PET160 b. HDPE150 c. PEC200

Fig. 1. Physical diagram of reinforcement breakage test

Table 1. Technical parameters of reinforcement

Reinforcement type	Nominal tensile strength (KN/m)	Elongation at Yield (%)	Rib length (mm)	Mesh length (mm)	Forming process
PET180	180	9	170	160	weld
HPDE150	150	14	400	390	stretch
PEC200	200	15	-	-	spin

2.2 Test Content

According to the results of field rolling test, the solid volume ratio can reach 79% by using 26t roller for 4 times of static rolling and 8 times of vibration rolling. On this basis, construction damage tests of three kinds of reinforcement were carried out under three working conditions: no protective layer, 5cm thick protective layer on the reinforcement, and 5cm thick protective layer on both the top and bottom of the reinforcement. A total of 9 groups of field full-size tests were carried out, and the size of the test site for each group was 22m×34m. Table 2 is the number of test sites, and Figure 2 is the picture of field tests.

Table 2. Test sites of reinforcement construction damage

Grille type	Ses-sion	Protective layer	Thickness of fill material
PET180	A1	No protective layer	50cm
	A2	5cm medium coarse sand on top	45cm
	A3	Lay 5cm of medium coarse sand on each side	40cm
HDPF150	B1	No protective layer	50cm
	B2	5cm medium coarse sand on top	45cm
	B3	Lay 5cm of medium coarse sand on each side	40cm
PEC200	C1	No protective layer	50cm
	C2	5cm medium coarse sand on top	45cm
	C3	Lay 5cm of medium coarse sand on each side	40cm

a. Lay reinforcement and protective layer

b. Lay filler

c. Crush

d. Dig the reinforcement

Fig. 2. Picture of reinforcement failure test site

2.3 Analysis of Result

(1) Packing Grading After Rolling.

After the rolling construction is completed, the filling body after the rolling is first dug and sampled, and the filling material grading test and compactness detection test are carried out. Figure 3 shows the packing grading curve of reinforcement damage test under different working conditions.

As shown in Figure 3, the grading curve: After rolling, the inhomogeneity coefficient C_u is 75 and the curvature coefficient C_c is 1.92, the inhomogeneity coefficient C_u is 19.4 and the curvature C_c is 1.86, and the inhomogeneity coefficient C_u is 23 and the curvature C_c is 1.20 of the fill material without the protection area. The gradation of fillers under different rolling conditions meets the requirements of $C_u \geq 5$ and C_c 1~3.

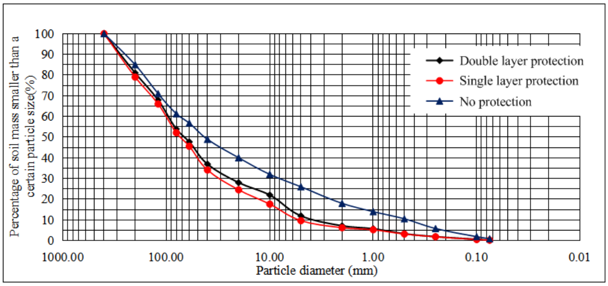


Fig. 3. Packing grading curve of reinforcement failure test

At the same time, 3 points were selected in each test area for solid volume rate test. Under different working conditions, the solid volume rate of the fill material is 79.33~80.25%, all of which are greater than 79%, indicating that the density of the fill after rolling meets the requirements.

(2) Apparent Description of Steel bar After Grinding.

According to the test content in Table 2, the field reinforcement construction damage test was carried out. After the completion of each test, the upper fill and protective layer were removed. The reinforcement should be well protected during the cleaning process, the damage and integrity of the reinforcement should be checked, and a typical fragment was cut from each sample of the reinforcement in the field damage test for apparent damage analysis and strength test. According to the provisions of Appendix D of BS8006, the apparent condition of the damage grille is divided into four types: ordinary wear, splitting, blunt trauma and cutting.

Figure. 4 shows the samples excavated after the filling construction of PET180 grid. Figure. a shows that there are protective layers above and below the reinforcement in zone A3, and the samples have a small amount of ordinary wear. Figure b shows that the upper part of the reinforcement in zone A2 is protected. The sample is mainly characterized by ordinary wear and splitting, with occasional blunt trauma. Figure. c shows that the reinforcement in area A1 has no protective layer, and the samples are mainly split, with serious common damage and blunt trauma. No severing damage was observed in the three tests.

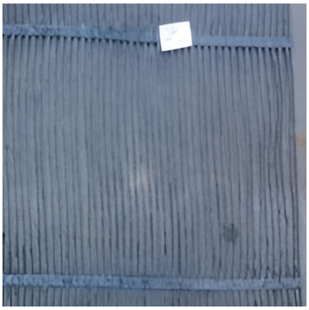
a. Upper and lower protective layers

b. Upper protective layer

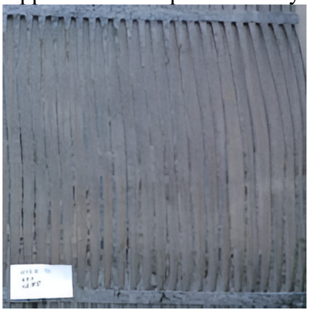
c. No protective layer

Fig. 4. PET grid sample diagram

Figure. 5 shows the samples dug after the HDPE150 geoglage filling construction. Figure. a shows that both the upper and lower reinforcement in zone B3 are protected, and the samples are mainly worn with occasional blunt trauma. Figure b shows that the upper part of the reinforcement in zone B2 is protected. The sample is mainly characterized by ordinary wear and splitting, with occasional blunt trauma. Figure. c shows that there is no protective layer for the reinforcement in area B1, and the samples are mainly common wear and blunt damage, with occasional splitting. No cutting damage was found in the three regional grid tests.



a. Upper and lower protective layers



b. Upper protective layer

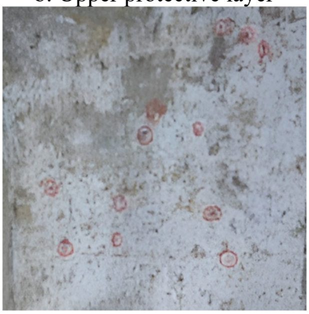
c. No protective layer

Fig. 5. HDPE grid sample diagram

The sample excavated after PEC200 geotextile filling construction is shown in Figure. 6. The damage modes of the sample are mainly ordinary wear and toppling. a sample of $1m^2$ is taken from typical parts and the size and number of toppling parts are observed.

a. Upper and lower protective layers

b. Upper protective layer



c. No protective layer

Fig. 6. Schematic diagram of PEC geotextile sample

From Figure. 4 to Figure. 6, it can be seen that the three kinds of reinforcement materials, PET180, HPDE150 and PET200, have the most serious damage when there is no protective layer. The protective layer of medium and coarse sand with a thickness of 5cm on top can reduce the apparent damage of construction, and the protective layer of coarse sand with a thickness of 5cm on top and bottom can significantly reduce the apparent damage of construction.

(3) Reinforcement Tensile Test.

CMT4305 microcomputer electronic universal testing machine was used for tensile test, and the tensile rate was 20mm/min. The tensile tests were carried out on the original sample, the sample after filling and rolling (no protective layer, upper protection, double protection) of the three types of reinforcement; Strip tensile test was used for geogrids, 6 single bar specimens were selected for each group of tests, and wide strip tensile test was used for geotextiles. Two groups of tests were carried out for each working condition of the three kinds of reinforcement, with a total of 24 groups. Table 3 and Figure 7 show the tensile test results of reinforcement under different working conditions, and Figure 8 shows the comparison between the mean tensile strength of different elongation and the mean maximum tensile strength.

Table 3. Table of tensile test results（Average value）

Grille type	Test field	Working condition	Tensile strength()kN/m)	Elongation(%)	2% Deformation tensile strength(kN/m)	5% Deformation tensile strength(kN/m)	Construction damage coefficient RF_{ID1}	Construction damage coefficient RF_{ID2}
PET 180	A0	Original sample	199.22	9.30	62.19	121.46	-	-
	A1	No protective layer	159.09	7.42	58.15	116.31	1.25	1.13
	A2	Upper protection	168.33	7.48	65.11	124.42	1.18	1.07
	A3	Double layer protection	171.76	7.67	61.74	121.87	1.16	1.05
HDPE150	B0	Original sample	165.40	14.50	35.41	75.79	-	-
	B1	No protective layer	140.12	12.79	34.46	70.82	1.18	1.07
	B2	Upper protection	147.75	12.84	35.19	73.02	1.12	1.02
	B3	Double layer protection	150.40	12.70	36.36	74.96	1.10	1.00
PEC 200	C0	Original sample	205.92	12.74	45.28	82.63	-	-
	C1	No protective layer	166.59	15.79	18.24	67.52	1.24	1.2
	C2	Upper protection	174.57	11.49	41.03	73.19	1.18	1.15
	C3	Double layer protection	181.23	13.02	36.09	80.33	1.14	1.10

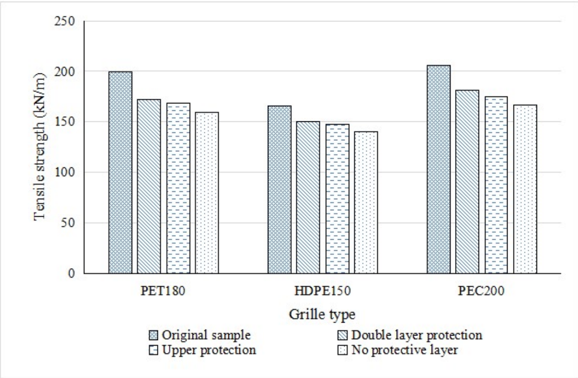


Fig. 7. Average tensile strength of grilles under different working conditions

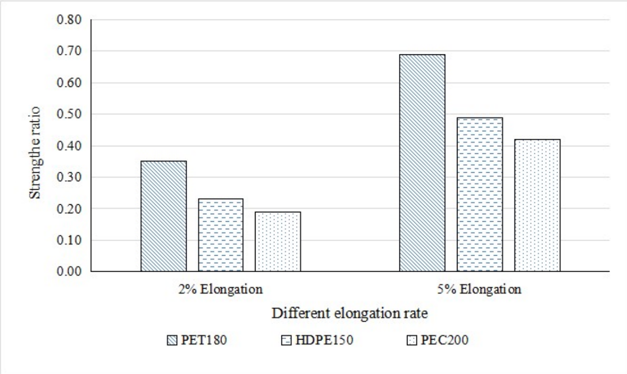


Fig. 8. Strength ratios of different elongation rates

It can be seen from Table 3, Figure 7 and Figure 8 that:

1) The tensile strength of the original reinforcement exceeded the nominal tensile strength, and the average measured tensile strength of PET180 was 199.22kN/m, exceeding 10.7%; The average measured value of HDPE150 is 165.40kN/m, exceeding 10.3%. The measured mean value of PEC200 is 205.92kN/m, exceeding 2.9%.

2) The average maximum elongation of the original PET180 grille is 9.3%, which is reduced to 7.5% after rolling, a decrease of 19.1%; The average maximum extension rate of the original HDPE150 grille is 14.5%, and it is reduced to 12.8% after rolling, which is reduced by 11.1%. The average maximum elongation rate of PEC200 geotextile is 12.7%, which is increased to 13.4% after rolling, an increase of 5.4%.

3) When the elongation rate is 2%, the tensile strength of PET180 grille is 35% of the maximum tensile strength, HDPE150 is 23%, and PEC200 is 19%; When the elongation rate is 5%, the tensile strength of PET180 grille is 69% of the maximum tensile strength, HDPE150 is 49%, PEC200 is 42%. It shows that the elongation of PET is small and the strength increases rapidly, but the test data are discrete and the strength stability is slightly poor. The elongation of PEC is too large and the strength increases slowly. In contrast, the strength and elongation of HDPE are in the middle, and the test parameters are stable, which may also be the reason why high-density polyethylene is used in China.

4) After rolling, the tensile strength of the reinforcement with a 5cm thick medium coarse sand protective layer above and below is slightly greater than that with only a 5cm thick medium coarse sand protective layer on the top of the reinforcement, and the values of the two are close, which is related to the rolling of the fill under the reinforcement; However, when there is no protective layer, the strength of the reinforcement decreases greatly, indicating that the protective layer on the reinforcement has a great influence on the strength.

(4) Construction Damage Coefficient of Reinforcement.

Compared with the average tensile strength of the original sample of reinforcement and the average tensile strength of the rolled reinforcement, the construction damage coefficient of the geoggrid can be obtained, and the calculation formula [15] is as follows:

$$RF_{ID} = \frac{T}{T_{dam}} \tag{2}$$

Where, RF_{ID} is the construction damage coefficient, T is the tensile strength of the sample before laying, and T_{dam} is the tensile strength of the sample after laying construction damage.

Figure. 9 shows the comparison of construction damage coefficients of PET180, HDPE150 and PEC200 grilles under three working conditions: upper protective layer, double protective layer and no protective layer. RF_{ID1} is the construction damage coefficient calculated from the measured tensile strength. RF_{ID2} is the construction damage coefficient calculated from the nominal tensile strength of reinforcement, which is used when the test data is lacking.

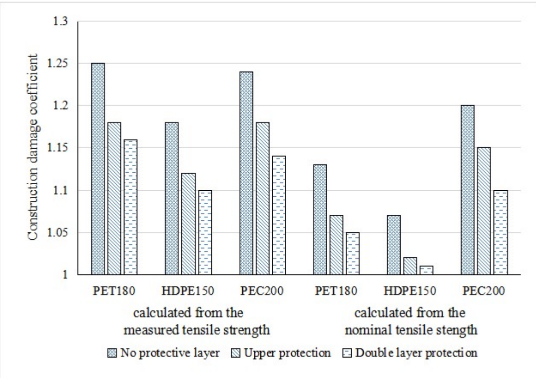


Fig. 9. Average construction damage coefficient of reinforcement under different working conditions

As can be seen from Figure 9:

1) The damage coefficient of PET180, HDPE150 and PEC200 is 1.25, 1.18 and 1.24 when no protective layer is installed. After the protective layer is installed, the construction damage coefficient is obviously reduced.

2) The construction damage coefficient of the grating under the two working conditions of PET and HDPE with a protective layer and a protective layer above and below is relatively close, the main reason is that before laying the reinforcement, the lower filler has been rolled and compacted, the filling surface is relatively flat, and there is no obvious edge and corner, so the lower filler has less damage to the grating. There is a great difference in the construction damage coefficient of the grating under two working conditions of PEC with protective layer on top and both on top.

According to $RFID_1/RFID_2$, the ratio of PET180 is 1.09~1.10, the ratio of HDPE150 is 1.10, and the ratio of PEC200 is 1.03~1.04, indicating that the design strength obtained is safe if the nominal tensile strength is reduced in the absence of test data.

3 CREEP REDUCTION COEFFICIENT OF REINFORCEMENT

The creep test of reinforced steel is to apply a constant static load to the sample under the conditions of 20±2°C and 50-70% relative humidity, and the load is evenly distributed over the entire width of the sample. The elongation of the sample is continuously recorded or recorded at specified time intervals. The load is maintained for 1000h or longer, and the fracture time is recorded if the sample breaks less than 1000h.

3.1 Test Device and Method

RDW20030 electronic creep endurance testing machine and microcomputer controlled electronic universal (tensile) testing machine CMT4305 were used in this test. The test equipment is shown in Figure 10 below. The load level adopts 3 levels of load, respectively using the ultimate load of 40%, 45% and 45%.

a. Schematic diagram of the whole machine

b. Grid sample in the environment

Fig. 10. Microcomputer-controlled electronic creep endurance testing machine

3.2 Test Results

Two sets of creep tests were carried out on PET180, HDPE150 and PEC200, and a total of six sets were carried out. The creep reduction coefficients of different reinforcement materials were obtained. Table 4 show the creep test results. RFCR1 is the creep reduction coefficient calculated from the measured tensile strength. RFCR2 is the creep reduction factor calculated from the nominal tensile strength of the reinforcement.

Table 4. Table of creep test results of bars

Grid type	Sample number	Material ultimate tensile strength (kN/m)	Lower limit of tensile strength for long-term allowable load with a design life of 106 hours (kN/m)	Creep reduction factor RF_{CR1}	Creep reduction factor RF_{CR2}
PET180	1#	189.20	106.80	1.77	1.68
	2#	194.34	107.27	1.81	1.68
HDPE150	1#	164.67	56.75	2.90	2.64
	2#	166.13	56.14	2.96	2.67
PEC200	3#	209.00	94.24	2.21	2.12
	4#	202.84	96.15	2.11	2.08

As can be seen from Table 4:

1) According to the measured tensile strength of reinforcement, the creep reduction coefficient of PET180 is 1.77-1.81, of PEC200 is 2.11-2.21 and of HDPE150 is 2.90-2.96.

2) According to the nominal tensile strength of the reinforcement, the creep reduction coefficient of PET180 is 1.68, that of PEC200 is 2.64-2.67 and that of HDPE150 is 2.12-2.08.

3) According to RFCR1/RFCR2, the ratio of PET180 is 1.07, the ratio of HDPE150 is 1.10, and the ratio of PEC200 is 1.03, indicating that in the absence of test data, if the creep reduction is carried out according to RFCR2, the calculated available strength is safe.

4) The creep property of PET is better than PEC and HDPE.

4 AGING REDUCTION COEFFICIENT OF REINFORCEMENT

In order to study the durability of reinforced materials, carbon black detection and UV resistance tests were carried out on PET180 and HDPE150 geogles respectively.

4.1 Carbon Black Content Test

Carbon black materials can fully absorb visible light and reflect ultraviolet light, and are generally added to geosynthetic materials as light shielding agents, which can improve the light stability of geosynthetic materials and extend the service life of geosynthetic materials. The carbon black content test of PET180 and HDPE150 grates was carried out by thermogravimetric method. Table 5 shows the test results of carbon black content in geogrid.

Table 5. Test results of carbon black content in geogrid

Grid type	Number of sample sets	Determination of carbon black (%)
PET180	3 groups	5.11~6.09
HDPE150	3 groups	2.14~3.16

It can be seen from Table 5 that the carbon content of PET is 5.11~6.09% and that of HDPE is 2.14~3.16, both of which meet the requirements of the specification by no less than 2%.

4.2 UV Resistance Test

Fluorescent ultraviolet lamp method was used to test the anti-ultraviolet performance of reinforced materials. Two groups of samples were taken from PET180 and HPDE150 respectively for testing, and their tensile strength and elongation were tested after 480 hours of exposure to ultraviolet lamps. Table 6 shows the anti-aging test results of reinforced materials.

Table 6. Results of anti-aging test of reinforced timber

Grid type	Sample number	reset condition		Ultraviolet radiation 480h		Strength loss rate (%)	Durability reduction factor RF_{D1}	Durability reduction factor RF_{D2}
		tensile strength (kN/m)	extend rate (%)	tensile strength (kN/m)	extend rate (%)			
PET180	1#	199.22	8.68	145.31	16.43	27.06	1.37	1.24
	2#			145.76	15.64	26.84		
HDPE150	3#	165.4	14.5	134.85	7.75	18.47	1.22	1.10
	4#			135.75	7.915	17.93		

As can be seen from Table 6:

1) The tensile strength of the two gegrates was lost to some extent after 480 hours of ultraviolet irradiation, and PET180 lost about 27%; The strength of the HDPE150 grid is lost by about 15% to 18%, and the elongation is reduced by nearly 1 times, indicating that the brittleness of the material increases after aging.

2) The aging reduction coefficient of PET180 and HDPE150 is 1.37 and 1.22, respectively, calculated according to the average tensile strength of the original. According to the nominal tensile strength, the aging reduction factor of PET180 is 1.24 and that of HDPE150 is 1.10.

According to RF_{D1}/RF_{D2}, the ratio of PET180 is 1.10 and the ratio of HDPE150 is 1.11, which indicates that when the test data is lacking, if the aging reduction is carried out according to RF_{CR2}, the calculated available strength is safe.

5 CONCLUSIONS

The following conclusions can be obtained through the full scale field damage test and the laboratory basic characteristic test study of the reinforcement:

1) The reinforcement material in the gravel reinforced structure can effectively reduce the construction damage of the reinforcement material in the gravel material under the condition of laying a 5cm thick medium coarse sand protective layer on top. However, setting protective layers on both the top and bottom has little effect on further reducing the construction damage of the reinforcement material, which may be related to the compaction of the lower filling body before the reinforcement material is laid.

2) The tensile strength of the original samples of geogrid PET180 and HPDE150 exceeds the nominal strength by 10%, and the geotextile PEC200 exceeds 3.0%; After rolling, the elongation of PET180 and HPDE150 grids decreased by 10-20%, indicating an increase in the brittleness of the grids after rolling.

3) When three types of reinforcement materials, PET180, HPDE150, and PEC200, are directly laid in crushed stone filling (without a protective layer), their average construction damage coefficients are 1.25, 1.18, and 1.24, respectively; After setting up the protective layer, the construction damage coefficient significantly decreased, with an average value of 1.10-1.18. The average creep reduction coefficients of PET180, HPDE150, and PEC200 reinforcement materials are 1.79, 2.93, and 2.16. The average aging reduction coefficients for PET180 and HPDE150 are 1.37 and 1.22.

4) PET180, HPDE150, and PEC200 reinforcement materials were used to calculate the comprehensive reduction coefficient based on measured tensile strength. The average values without a protective layer were 3.07, 4.22, and 3.35, respectively. After setting a protective layer, the average values were 2.85, 3.97, and 3.14, respectively. The comprehensive reduction coefficient decreased by about 7.0%.

5) If there is a lack of measured data, when calculating the reduction coefficient using the nominal tensile strength of the reinforcement, the average comprehensive reduction coefficient without protective layer is 2.60, 3.47, and 3.15; The average values after setting the protective layer are 2.44, 3.30, and 2.96. In engineering, the nominal tensile strength of reinforcement materials and the measured comprehensive reduction coefficient are usually used to calculate the available strength of reinforcement materials, which is relatively safe, with a safety margin of about 1.06.

6) The elongation of polyester fiber PET is small and the strength growth is fast, but the experimental data is discrete and the stability is slightly poor; The extension rate of geotextile PEC is high, but the strength growth is slow; In contrast, the strength and elongation of high-density polyethylene (HPDE) are in the middle, and the experimental parameters are stable, which may be the reason why high-density polyethylene is commonly used in reinforced structures in China.

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