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Product Performance

Assessments of long-term filtration performance of degradable prefabricated geotextile drains

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Abstract

A smart geotextile for hydraulic end-use applications, such as filtration and drainage, has been manufactured. For filtration applications, biodegradable prefabricated vertical drains (PVDs) were fabricated using special conditioned geotextile filter and plastic cores to improve their degradability. Aliphatic polyester-based PVDs showed higher tensile strengths than starch-based PVDs. Biodegradable PVDs showed lower hydraulic properties than normal PVDs, however, the magnitude of the difference was not large. In terms of their chemical resistance and biodegradation, the biodegradable PVDs were better than typical PVDs. Compared to geonet composites, smart geotextiles could be the ideal geosynthetics for drainage applications on side sloping areas and for the protection of geomembranes in waste landfills.

Keywords: Smart geotextile; Filtration; Biodegradable prefabricated vertical drains (PVDs); Geonet composites; Waste landfills

1. Introduction

The general method used in the rapid consolidation of saturated fine-grained soils or soft soils is prefabricated vertical drains (PVDs). These are inserted into the ground with their ends protruding out of the surface, with water being forced out of them under pressure, as shown in Fig. 1. The plastic cores of the PVDs must possess certain properties, such as sufficient drainage capacity, large filtration area, and high tenacity. In addition, they must also have excellent installation performance and resistance to acidic or alkaline solutions and salt water at high and low temperatures [1]. Most commercial PVDs cannot be degraded after completing their drainage function, and this is a serious and important factor in soil and ground pollution [2]. PVDs usually consist of plastic fluted cores and nonwoven geotextile filters, which surrounded the cores, as shown in Fig. 2.

It is therefore desirable to develop smart PVDs that can decompose after their drainage function is over, while also having the optimum tensile strength during their service life. To achieve this, biodegradable polymeric materials have been used to manufacture the proposed drainage geosynthetics with tailored mechanical properties, as the tensile strength of PVDs decreases with the addition of biodegradable additives [3].

The geotextiles that surround the plastic core should also have environmentally friendly and high absorbent properties that are not detrimental to tensile strength. We have investigated the properties of starch and unsaturated polyester as biodegradable additives that were blended

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Fig. 1. Photographs of PVDs installed in the field.

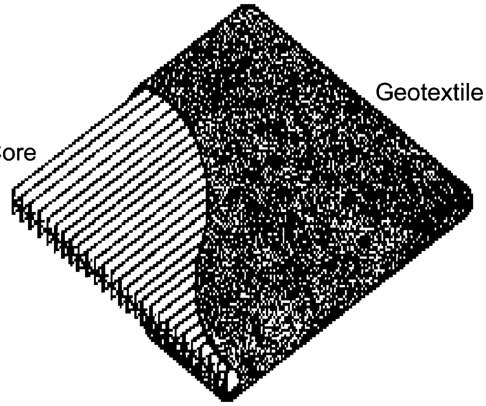


Fig. 2. Drawing of a typical PVD.

with high-density polyethylene (HDPE) and polypropylene (PP) under optimum composition ratios to improve the environmental properties of the plastic cores. The geotextile filters were prepared by blending highly absorbent cotton fibers with PP fibers.

The mechanical and hydraulic properties, and the degree of degradation of the biodegradable PVDs were evaluated and compared to those of commercial PVDs having no biodegradable function.

2. Experimental

2.1. Preparation of the biodegradable geotextile filters

Generally, polypropylene spunbonded nonwovens are used as PVD filters, and these have excellent tensile properties. However, these filters do not degrade when in the ground after consolidating the soft soils, and this is a major cause of environmental pollution. To minimize the pollution from underground synthetic filters, waste cotton fibers were used as a biodegradable fiber.

Table 1a
Specification of the biodegradable plastic cores: Starch-based

Composition (%)	Plastic core		
	SHP-1	SHP-2	SHP-3
Starch	3.4	7.6	13.2
HDPE	2.2	5.4	9.4
PP	94.4	92.0	77.4

SHP denotes the composition, i.e. starch/HDPE/PP.

The composition of the biodegradable geotextile filter had a special blend ratio by weight of cotton/PP = 30/70. The biodegradable geotextile filters were fabricated using a needle punching process with a specified needle punching condition.

2.2. Preparation of biodegradable plastic cores and biodegradable geotextile vertical drains

To improve the degradability of the plastic core, starch and aliphatic polyester-based polypropylene cores were manufactured using different blend conditions, as shown in Table 1. The polymers used in this work were commercial grade HDPE and PP.

Table 1b
Specification of the biodegradable plastic cores: Aliphatic polyester-based

Composition (%)	Plastic core		
	APES-1	APES-2	APES-3
Aliphatic polyester	10.2	20.3	30.5
PP	89.8	79.7	69.5

APES denotes the composition, i.e. aliphatic polyester/PP.

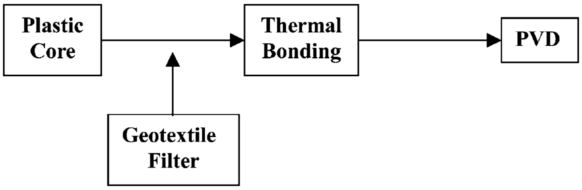


Fig. 3. The manufacturing process of the PVDs.

The geotextile filter was wrapped around the inner plastic core, as shown in Fig. 2. The manufacturing process of the biodegradable PVD is shown in Fig. 3. Table 2 shows the specifications for the biodegradable PVDs, which were made of biodegradable geotextile filters and starch and aliphatic polyester-based polypropylene cores.

2.3. Assessment of serviceability and performance

2.3.1. Mechanical properties

The tensile properties and the burst and tear strengths of the biodegradable geotextile filter and plastic cores were measured in accordance with standards procedures ASTM D 4632, ASTM D 3786, and ASTM D 4533, respectively. The tensile properties of the biodegradable PVDs were measured in accordance with standards procedure ASTM D 4632.

2.3.2. Hydraulic properties

The transmissivities of the PVDs at 10 and 300 kPa were examined in accordance with standards procedure ASTM D 4716. The apparent opening size (AOS) and the permittivities of the biodegradable geotextile filter were measured in accordance with standards procedures ASTM D 4751 and D 5493, respectively.

2.3.3. Chemical resistance

The chemical resistance of the biodegradable PVDs in acidic and alkaline solutions was estimated from the decrease in weight after immersion for 5 h in H_2SO_4 (30%), HCl (20%), NaOH (40%), NaCl (10%), and distilled water at 25 °C.

2.3.4. Degree of biodegradability

The degree of degradability of the biodegradable PVDs in soft soils was estimated by tensile strength retention after 730 d reclamation. The soft soils of a field in South Korea were selected to perform this experiment. To compare the properties with those of a commercial and typically used PVD, a general PVD having no biodegradability was adopted.

Table 2
Specifications of the biodegradable PVDs

Prefabricated vertical drain	Composition		Weight (g/m^2)
	Filter	Plastic core	
PVD-1	Staple fibers Cotton fibers (25%)+Polypropylene fibers (75%)	SHP-1	
PVD-2		SHP-2	
PVD-3		SHP-3	
PVD-4		APES-1	230.5
PVD-5		APES-2	
PVD-6		APES-3	
PVD-7	Filament fibers Polypropylene fibers (100%)	Polypropylene	

PVD-7 is commercial PVD that has no biodegradability.

3. Results and discussion

PVDs are able to have a vertical drainage function because of the capillary action between the geotextile filter and the plastic core, as shown in Fig. 4. After removing the underground water using the PVD, the soft soil would be sufficiently consolidated for installations to be carried out and for civil engineering construction to take place [4]. Fig. 5 shows a biodegradable geotextile filter, a plastic core and a geotextile that were fabricated in this study.

The mechanical properties of the geotextile filter and the plastic cores are shown in Table 3. From Table 3, we can see that the aliphatic polyester-based plastic cores have better mechanical performance than the starch-based plastic cores.

In addition, the results in Table 3 are related to the morphology of these two types of plastic core, as shown in Fig. 6, and the aliphatic polyester-based plastic core,

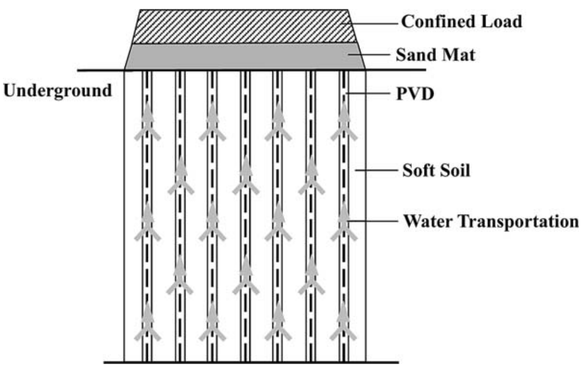


Fig. 4. Principle of vertical drainage using a geotextile vertical drain.

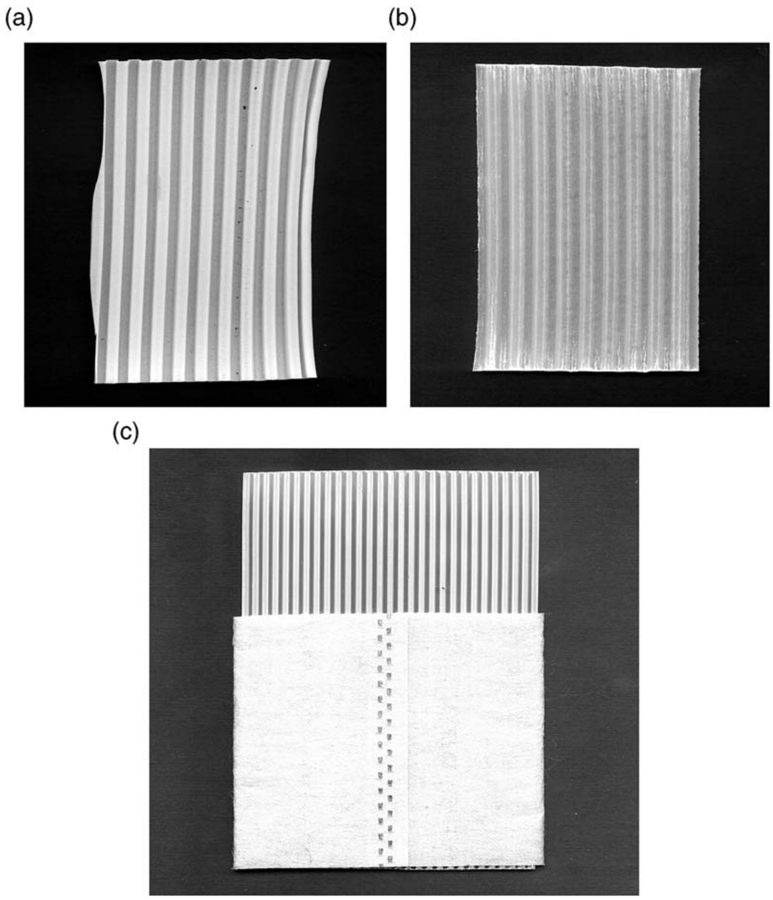
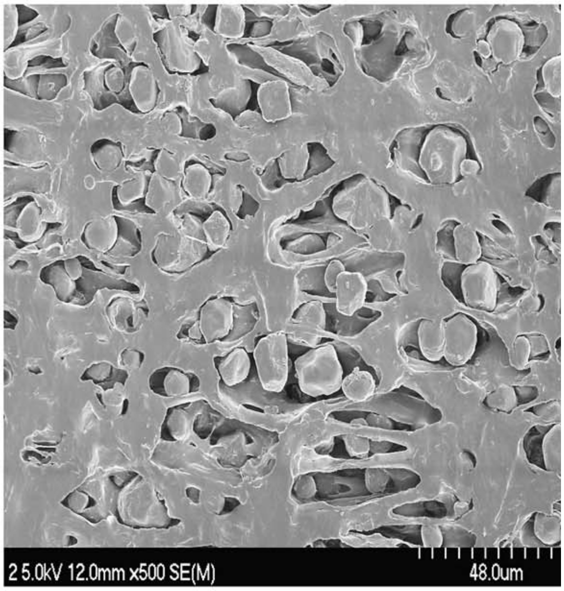


Fig. 5. Photographs of: (a) a starch-based plastic core, (b) an aliphatic polyester-based plastic core, and (c) a geotextile vertical drain.

Table 3
Mechanical properties of the geotextile filters and plastic cores

Material		Mechanical property			
		Tensile properties		Bursting strength (kg)	Tear strength (kg)
		Strength (kg)	Strain (%)		
Geotextile filter		28.5	32.4	16.7	22.4
Plastic core	SHP-1	56.4	6.2	37.2	24.7
	SHP-2	52.3	9.8	35.8	22.2
	ASP-3	41.5	13.6	30.6	17.4
	APES-1	64.3	7.8	42.9	28.9
	APES-2	66.7	6.1	45.8	31.2
	APES-3	59.4	5.3	40.6	26.3

(a)



(b)

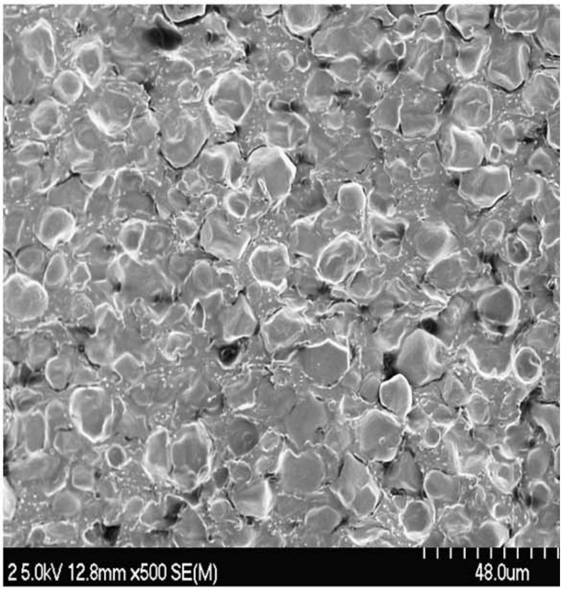


Fig. 6. Morphologies of: (a) a starch-based plastic core, SHP-1, and (b) an aliphatic polyester-based plastic core, APES-2.

APES-2, shows better miscibility than the starch-based plastic core, SHP-1.

Table 4 shows the tensile properties of the PVDs that were made of the biodegradable geotextile and the starch and aliphatic polyester-based plastic cores. It can be seen that the aliphatic polyester-based PVDs show excellent tensile strength, which was better than the starch-based PVDs. This is because of the excellent mechanical properties of the aliphatic polyester-based plastic cores. However, samples PVD-1 to PVD-6 do not show better tensile strength than sample PVD-7, and this is because of the biodegradable compositions of samples PVD-1 to PVD-6. The tensile strength is therefore related to the geotextile filter and the plastic core of PVD-7.

Table 4
Tensile strength of the PVDs

Prefabricated vertical drain	Tensile strength (kg)
PVD-1	202.3
PVD-2	196.5
PVD-3	182.7
PVD-4	216.3
PVD-5	224.5
PVD-6	237.3
PVD-7	356.8

Table 5 shows the transmissivities of the PVDs and AOS, and the permittivities of the geotextile filters. Here, the AOS value of the biodegradable geotextile filter was similar to that of sample PVD-7, but the permittivities and transmissivities of sample PVD-7 were higher than those of samples PVD-1 to PVD-6. It is thought that this decrease in the hydraulic properties of samples PVD-1 to PVD-6 is from the expansion of the biodegradable plastic core swelling in water. This was especially so for the starch-based plastic core, and this swelling hinders water transportation by capillary action.

Table 6 shows the chemical resistances of samples PVD-1 to PVD-7 deduced from the weight decrease after chemical attack with different chemical solutions. From these results, we can see that samples PVD-4 to PVD-6 show excellent resistance to the chemical solutions, but samples PVD-1 to PVD-3 are attacked by the alkaline solutions.

Table 7 shows the degree of biodegradation of the PVDs in field soils. For samples PVD-1 to PVD-6, with the higher composition of starch and aliphatic polyester, better biodegradation was observed.

From this result, we can see that samples PVD-1 to PVD-6 show excellent biodegradation results, better than the typical PVD, sample PVD-7, and this is because of the biodegradable composition of the PVD samples, samples PVD-1 to PVD-6.

4. Conclusions

Biodegradable prefabricated vertical drains were prepared and assessed. The experimental results are summarized as follows:

1. In the mechanical property tests, e.g. tensile properties and bursting and tear strength, the aliphatic poly-

Table 5
Transmissivities of the PVDs and AOS, and the permittivities of the geotextile filters

Material		Hydraulic properties			
		Transmissivity (cm^3/s)		AOS (O_{90}, μm)	Permittivity (m/s)
		10 kPa	300 kPa		
Geofilter filter		38.5	23.4	74.3	1×10^{-3}
PVD	PVD-1	166.5	121.3		
	PVD-2	166.3	122.2		
	PVD-3	167.2	121.5		
	PVD-4	167.4	122.7		
	PVD-5	167.2	122.5		
	PVD-6	167.3	122.3		
	PVD-7	182.3	136.9	78.6	1.3×10^{-3}

Table 6
Weight decrease of the PVDs with different chemical solutions

PVD	Solution				
	H_2SO_4 (30%)	HCl (20%)	NaOH (40%)	NaCl (1%)	Distilled water
PVD-1	1.8	1.2	2.7	0.8	1.2
PVD-2	1.7	1.5	2.8	0.7	1.5
PVD-3	1.8	1.5	3.2	0.6	1.8
PVD-4	0.8	0.6	1.9	0.8	0.8
PVD-5	0.7	0.5	2.2	0.8	1.0
PVD-6	0.6	0.5	2.3	0.7	1.0
PVD-7	1.8	1.3	2.5	0.8	1.2

Table 7
Degree of biodegradation of the PVDs in field soils

PVD	PVD-1	PVD-2	PVD-3	PVD-4	PVD-5	PVD-6	PVD-7
Tensile strength retention (%)	22.7	18.6	14.2	24.3	22.5	20.3	84.6

ester-based plastic cores, APES-1 to APES-3 were better than the starch-based plastic cores, SHP-1 to SHP-3.
2. In the tensile strength tests, the aliphatic polyester-based samples, PVD-4 to PVD-6, showed higher values than the starch-based samples, PVD-1 to PVD-3.
3. In the hydraulic property tests, e.g. transmissivities, AOS, and permittivities, the biodegradable samples, PVD-1 to PVD-6, showed lower values than the typical sample, PVD-7, but the differences among the PVDs were not large.
4. In terms of their chemical resistance and biodegradation, the biodegradable samples, PVD-1 to PVD-6, were better than the typical sample, PVD-7.

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