PORE SIZE OF WOVEN GEOTEXTILES VARIED WITH TENSILE LOADS

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ABSTRACT

The changes of pore size in woven geotextiles under tensile loads were measured accurately by digital image analysis. The geotextiles were stretched to maintain 3%, 6%, 9% and 12% in-plane uniaxial tensile strains, whose results were compared with those from unstrained specimens. The characteristics of change were figured out by several parameters, including percent open area, pore size distribution and characteristic opening sizes. The percent open area and characteristic opening sizes increase approximately linearly with the tensile strains. Furthermore, the smaller the pores are, the larger the rate of increases will be. The pore size distributions move towards the direction of the larger open sizes when the stain increases. The change of the pore size results from three elements, which are the rotation of slit film, tensile axial strain and lateral strain of the warp film. The analytic solution of the rate of change of pore area under tensile strains was studied. It concludes to a negative correlation between the rate of change of pore area and the length of pore side.

Keywords: Opening size, uniaxial tensile strain, woven geotextile, digital image analysis, mechanisms analysis

INTRODUCTION

The knowledge of pore sizes of geotextiles is requested to meet several criteria in filtration applications, including permeability, retention and anti-clogging capabilities (Robert 1998). The characteristic opening size can be influenced significantly by tensile strain. But the characteristic opening size is commonly determined under unstrained condition, which results in the criteria that cannot be satisfied.

As discussed by Fourie (1999), the opening size for thicker geotextiles decreases with increasing biaxial tensile load, whereas the opposite occurs for thinner geotextiles. Wu's (2008) experimental results illustrate the increase in pore size and average flow rate through plain geotextiles with the increase in tensile strain, which means the opening size becomes larger under tensile stress. A number of methods have been developed to test the changes in pore size subjected to tensile loads (Wu et al. 2008, Fourie 1997, 1999). The digital image analysis is a direct and accurate method among them (Aydilek 2002). The pore sizes of geotextiles have been tested by image analysis (Aydilek 2002, 2004). The digital image method was chosen to study the changes of pore size under tensile loads in woven geotextiles in this paper. The law and characteristic of pore changes were summarized, and the mechanisms of changes in woven geotextiles were analyzed.

MEASUREMENT OF OPENING SIZES

Materials Used

Table 1 Physical and mechanical parameters of woven geotextiles

	Thickness (mm)	Mass per unit area (g/m^2)	Warp tensile strength (kN/m)	Weft tensile strength (kN/m)	Density of slit-film (kg/m^3)
W_{150}	0.27	159.4	25.3	22.5	900
W_{250}	0.58	245.5	47.2	43.8	900

Two woven slit-film geotextiles made of polypropylene were employed in this study. They are designated as W_{150}, W_{250}, which means the masses per unit area of the two geotextiles are approximately 150 g/m^2 and 250 g/m^2. Details of the geotextiles used are described in Table 1. The strained geotextiles were obtained by stretching the geotextiles in the warp direction at the rate of

10mm/min. The tensile stress-strain relationships of woven geotextiles are shown in Fig. 1. The peak strains of W_{150} and W_{250} were 12.9% and 13.3%, respectively. Accordingly, the in-plane uniaxial tensile strains 3%, 6%, 9% and 12% were selected to study the influence of strains on pores.

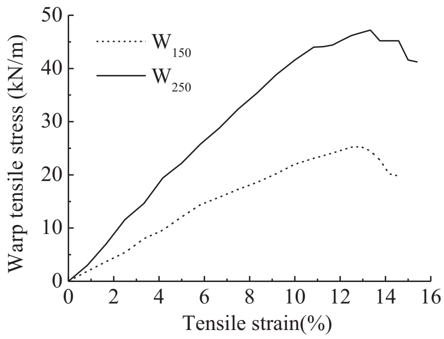


Fig. 1 Tensile stress-strain relationships of woven geotextiles

Image Analysis Method

The pore structure images of each strain were captured by a digital single-lens reflex camera. There are 10 specimens for each strain. Firstly, the true color images were turned into gray images. Secondly, the thresholding operation produced binary images from gray images. After filtering treatment (opening and closing), the noises in binary images were removed. Then the area of each pore could be read accurately. The effect of image treatment is shown in Fig. 2. The differences between 0% and 12% strains can be seen in Fig. 3. The statistical analysis of the pore area was used to study the changes in pore size.

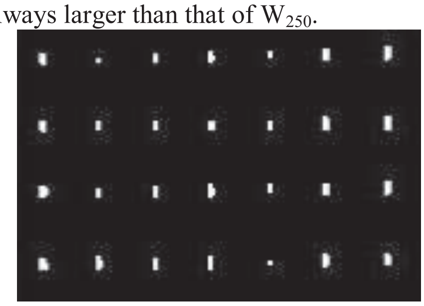
(a) Original image (b) Image after treatment

Fig. 2 Effect of image treatment

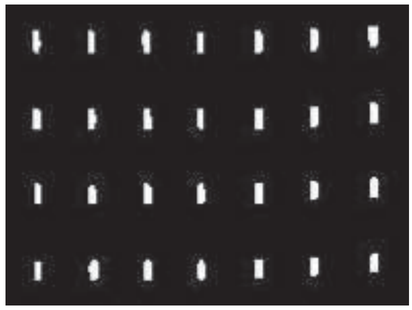
EXPERIMENTAL RESULTS

Percent open area (POA) and pore-size distribution (PSD) are two important parameters to determine pore-opening structure of woven geotextiles. Most of the current filter design criteria use characteristic opening sizes (i.e., O_{30}, O_{50} and O_{95}). Hence image analysis has been used to determine the POA, PSD, and characteristic opening sizes of woven geotextiles taking advantage of their two-dimensional structure.

Figure 3 illustrates that the opening sizes become larger under tensile stress. Percent open area (POA) is the ratio of open area to total area of woven geotextile. POA is directly correlated to permittivity (Aydilek 2004). The percent open areas of woven geotextiles increased approximately linearly with the increase in the tensile strains (Fig. 4). The POA of W_{150} is always larger than that of W_{250}.



(a) ε =0%



(b) ε =12%

Fig. 3 Pore size of W_{150} with (a) 0% and (b) 12% tensile strains

Figure 5 indicates the pore size distributions moved towards the direction of the larger open sizes. The shapes of the PSD curves W_{150} did not obviously vary under different strains, which means the pores of different sizes become uniformly larger. But in W_{250}, the lower right parts of the PSD curves did not seem to move, which means some small pores still exist. But that does not mean the pore size of that part does not increase. Small pores are newly created. Due to the thickness of W_{250}, some pores cannot be seen without strain. As the strain increases, they are stretched open, and can be measured. That is why there are always some small pores.

Figure 6 indicates the pores of different sizes become larger under tensile strain. The characteristic opening sizes increase approximately linearly with the tensile strains. The rates of increase of O_{30}, O_{50}

and O_{95} in W_{150} are 5.9, 4.8 and 3.7, respectively. The rates of increase of O_{30}, O_{50} and O_{95} in W_{250} are 12.4, 9.4 and 7.3, respectively. The smaller the characteristic opening size is, the larger the rate of increase will be. That means the influence of tensile strain on small pores is stronger than on large pores. The rates of increase of the thicker geotextiles are larger than those of the thinner ones.

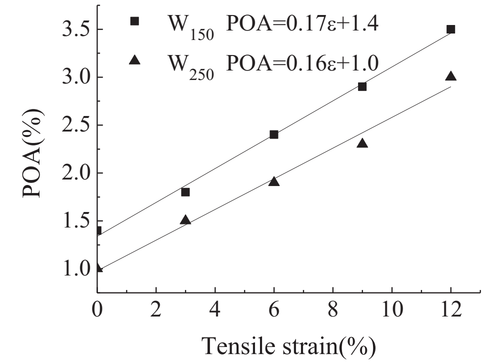
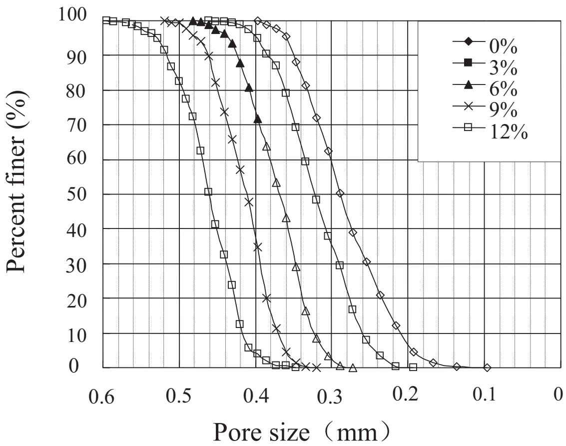
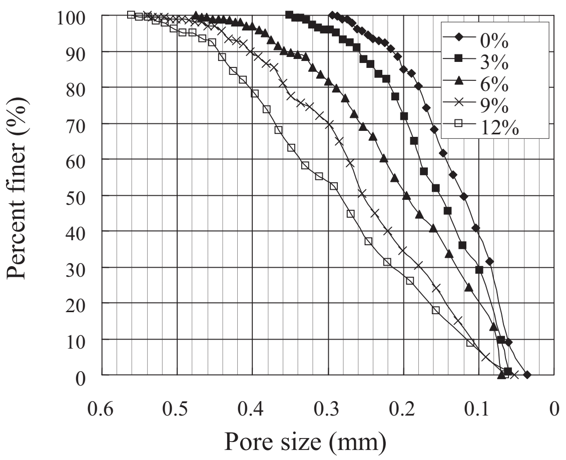


Fig. 4 Relationship between POA and tensile strains

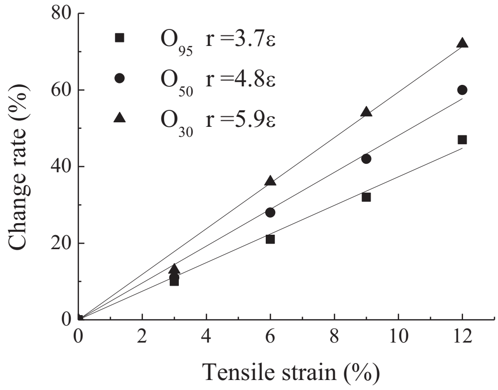


(a) Pore-size distribution of W_{150}

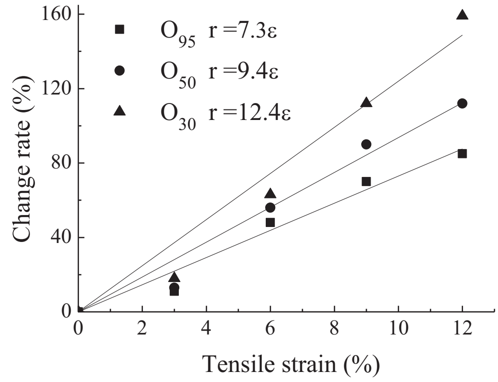


(b) Pore-size distribution of W_{250}

Fig. 5 Pore size distribution of woven geotextile under tensile strains



(a) Woven geotextile W_{150}



(b) Woven geotextile W_{250}

Fig. 6 Relationship between the rate of change of characteristic open sizes and tensile strains

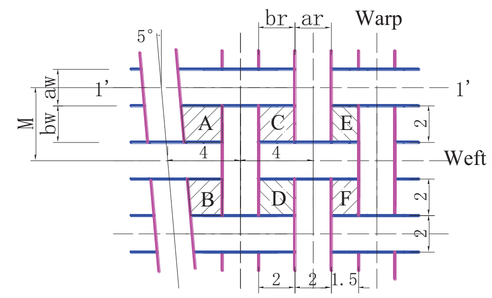
MECHANISMS ANALYSIS

The warp and weft slit films are not strictly perpendicular to each other, hence the tensile loads can result in the rotation of slit films. The changes in the area of pore size result from three elements, which are the rotation of slit film, tensile axial strain and lateral strain of the warp slit film. Figure 7 is given as an example to explain the mechanism. The pore structure of a geotextile changes from Fig. 7a to Fig. 7b under tensile stress. The “A” and “B” pores are influenced by the above three elements, and “C”~“F” pores are only influenced by the latter two.

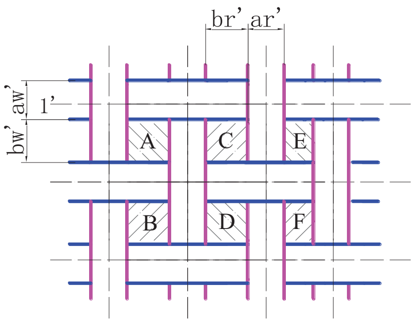
The sizes of pores were assumed to be dimensionless, as shown in Fig. 7a. The width of the slit film was set as 2, and the Poisson's ratio was set as 0.4 (Giroud, 2004). The angle of the film rotation on the left of “A” and “B” was assumed to be 5°. When the slit films do not rotate, the rate of change of pore area can be calculated by the following equations:

$$x = \frac{A'}{A_0} - 1 = \varepsilon + \frac{\varepsilon a_w}{b_w} + \frac{\varepsilon \nu (1+\varepsilon) a_r}{b_r} + \frac{\varepsilon^2 \nu a_r a_w}{b_r b_w} \quad (1)$$

where a_r, a_w are the width of slit film in warp and weft direction, respectively. b_r, b_w are the length of pore side in warp and weft direction. A_o , A' are the original and strained pore area, respectively. x is the rate of change of pore area. Eq. 1 shows a negative correlation between the rate of change of area and the length of pore side. It can be concluded that the rate of change x decreases when the length of pore side b_r and b_w increase.



(a) Unstrained woven geotextile



(b) Strained woven geotextile

Fig. 7 Effect of strain on woven geotextile

Table 2 Changes of pore areas

	A	B	C	D	E	F
Ao	4.342	3.64	4	4	3	3
A'	4.992	4.992	4.992	4.992	3.792	3.792
x	0.228	0.272	0.248	0.248	0.264	0.264

The changes of pore areas are shown in Table 2. The smaller the pores are, the larger the rate of change will be. The rotation of slit film influences more on the smaller pores than the larger ones, comparing the change of pore “A” and “B”. It also seems that the tensile axial strain and lateral strain influences more on the smaller pores than the larger ones, by comparing pore “C” and “E”. That coincides with the experimental results.

CONCLUSIONS

The characteristic opening sizes and percent open area increase approximately linearly with the tensile strains. The pore size distributions move towards the direction of the larger open sizes. The smaller the pore size is, the larger the rate of change will be. The rates of increase of characteristic opening sizes in the thicker geotextiles are larger than those of the thinner ones.

The changes in the area of pore size result from three elements, which are the rotation of slit film, tensile axial strain and lateral strain of the warp film. Each of the factors influences more on the smallest pores. The analytic solution shows a negative correlation between the rate of change of area and the length of pore side.

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REFERENCES

Aydilek A.H., Oguz S.H., Edil T.B. (2002). Digital image analysis to determine pore opening size distribution of nonwoven geotextiles. Journal of Computing in Civil Engineering, 16(4): 280-290.

Aydilek A.H., Edil, T.B. (2004).Evaluation of woven geotextile pore structure parameters using image analysis. Geotechnical Testing Journal, 27(1): l-l2.

Fourie A.B., Addis P.C. (1997). The effect of in-plane tensile loads on the retention characteristics of geotextiles. Geotechnical Testing Journal 20(2): 211-217.

Fourie A.B., Addis P.C. (1999). Changes in filtration opening size of woven geotextiles subjected to tensile loads. Geotextiles and Geomembranes, 17(5): 331-340.

Giroud J.P. (2004). Poisson's ratio of unreinforced geomembranes and nonwoven geotextiles subjected to large strains. Geotextiles and Geomembranes, 22(4): 297-305.

Robert M.K. (1998). Designing with Geosynthetics. Prentice Hall, New Jersey, USA.

Wu C.S., Hong Y.S., Wang R.H. (2008).The influence of uniaxial tensile strain on the pore size and filtration characteristics of geotextiles. Geotextiles and Geomembranes, 26(2): 250-262.