Fibers and Polymers 2005, Vol.6, No.4, 313-317

Study on Anisotropic Creep Behavior of Nonwoven Geotextiles

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(Received September 14, 2005; Revised November 20, 2005; Accepted November 27, 2005)

Abstract: The anisotropy in creep behavior of two types of nonwoven fabrics (needle-punched and thermobonded spun laid) has been studied. It has been observed that the amount of time dependent extension depends on the direction, amount of loading and the structure of nonwoven the fabrics. The time dependent extension (creep) for the nonwoven fabric increases with the increase in amount of load. The higher initial extension and creep are observed for needle-punched nonwoven fabric as compared to thermobonded spun-laid nonwoven fabric. The creep behavior of needle-punched nonwoven shows a logarithmic relationship with time, but the thermobonded spun-laid nonwoven fabric does not show such logarithmic relationship. For a particular fabric, the creep is dependent on the fiber arrangement and is minimum in the direction in which the proportion of fiber is maximum and visa versa.

Keywords: Anisotropy, Nonwoven, Creep, Geotextiles, Needle-punched, Thermobonded spun-laid

Introduction

Geotextiles are permeable textile structures made of polymeric materials and are used in civil engineering applications in conjugation with soil, rocks and other geotechnical materials for improving the engineering performance of the civil engineering works. Over the years there are many specific application areas for geotextiles have been developed where the fabric at least performs one of the four functions, i.e., separation, reinforcement, filtration, and drainage. However, in most of the cases, geotextiles perform more than one function at a time and in many cases, all the four functions are important although their relative importance may vary. For geotextiles applications, nonwoven fabrics account for about 80 % of the fabric used as geotextiles. Most of these fabrics are spun-laid continuous filament fabrics.

Mechanical properties in general and tensile properties in particular, of the nonwoven geotextiles are of considerable interest for their satisfactory performance as constructional materials. Perhaps the single most important property of a geotextile is its tensile strength. Most geotextile applications rely on this property either as a primary function (as in reinforcement applications) or as a secondary function along with separation, filtration or drainage. Most fibers, including natural fibers, are based on well-known polymeric materials. The polymers show a time-dependent behavior in mechanical properties and hence are said to be "visco-elastic". This is clearly seen in the creep (monotonically increasing strain) behavior of a fiber under constant stress, or the stress-relaxation that occurs in a fiber held at constant strain. Most polymers are prone to creep as a result of relatively weak inter-molecular forces acting between segmental units. The ability of the material to withstand loads without excessive creep is a major factor in material selection and design of a geotextile. When a fabric is subjected to a constant load, there is an instantaneous strain which occurs upon loading due to the structural rearrangement in the fabric and instantaneous strain in the polymer upon loading. Under sustained load, the strain in the sample increases with time and fabrics can rupture on sustained loading over the period of time at loads much lower than their short term failure loads. Also, the nonwoven fabrics, in general, show anisotropy in their characteristics. A number of studies [1-12] report the creep behavior of different types of nonwoven fabrics, but the information regarding the anisotropy in creep of nonwoven fabrics is limited. Therefore, it is necessary to study the anisotropy in creep behavior of nonwoven fabrics. Thus the main objective of this study was to investigate the anisotropy in creep behavior of needle punched and thermobonded nonwoven geotextiles at different levels of load.

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Experimental

Material

Two types of nonwoven geotextiles, i.e., polypropylene staple fiber needle punched and polyester thermobonded spun-laid nonwoven, are used in the present study. The details of the properties of fabrics are given in Table 1.

Table 1. The details of the properties of fabrics

Parameters	Needle punched fabric	Thermobonded fabric
Fiber linear density, denier	1.20	–
Fiber length, mm	90	–
Fabric weight, g/m^2	190	195
Needling density, per cm^2	100	–
Depth of needle penetration, mm	11.5	–
Fabric thickness, mm	4.47	0.54
Fabric tensile strength, kgf	88.54	209
Fabric breaking extension, %	158	48.8

Testing

Tensile Testing

Tensile properties of nonwoven geotextiles were measured using wide-width strip tensile test method, as specified in ASTM D4595. The basic distinction between this method and other methods is the specimen width. This width, by contrast, is greater than the gauge length of the specimen. Some fabrics used in geotextiles have a tendency to neck down (contract) under a force in the gauge length area. The greater width applied over here minimizes the contraction effect.

Creep Testing

The fabric samples of 250 mm × 200 mm size were cut such that the longer dimension is in the direction in which tensile load was require to be applied during creep test. An aluminum template 100 mm × 250 mm was placed between both the plates to obtain 100 mm gauge length. The fabric samples were fixed between two grips of size 225 mm × 100 mm × 15 mm. A toothed face is especially finished in the grips to provide firm grip to the fabric specimen. One of the grips was fixed to a fixed part of the frame and the other grip was connected to a chain passing over a sprocket wheel to hold the hook of weight-tray rod. Number of different weight block of 5, 10 and 20 kg of cast iron is used for loading. A slot of 15 mm is cut from one side up to the centre of each weight to insert it in the weight-tray rod. The specimen along with the grips is kept in the horizontal plane to align the plane of the fabric in the direction of tensile load; a portable hydraulic jack of 1.5 ton capacity with strong supporting platform was used for load application. Finally to start the creep test, the load is transferred onto the specimen by releasing pressure of the jack. After the load was applied on the fabric specimen, instantaneous deformation was recorded. A Vernier Caliper was used to measure the longitudinal deformation. The extension of the fabric sample was recorded by measuring the gap between the edge of the movable and fixed grips. The measurements were made at three places i.e., at both edges and the centre point. The average of these measurements was recorded as the extension of the fabric specimen.

The anisotropy of the creep behavior was studied at different angles with the machine direction of fabrics, i.e., 0 °, 30 °, 60 ° and 90 °. The fabric samples were cut at machine direction (0 °), cross-machine direction (90 °) and two other directions, i.e., 30 ° and 60 ° with the machine direction. The loading of these fabrics was done with different levels of constant loads, i.e., 30 %, 45 % and 60 % of tensile strength along the machine direction. The extensions due to application of load were recorded immediately and after different time intervals, i.e., 30 sec, 1 min, 2 min, 5 min, 10 min, 15 min, 30 min, 1 h, 2 h, 5 h, 1 day, 2 days, 5 days, 10 days, 15 days and 20 days. The average of five readings was taken for a particular sample.

The structural changes in the fabric were studied by observing the changes in the fiber orientation in the fabric before and after creep. The fabric specimen under test was marked at five different places and the images of the marked places were taken with the help of a microscope (Hi-scope) at the magnification of 100× so the individual fibers can be identified and their angles with respect to machine direction were observed on visual inspection. Actual angles of the fibers are noted and tabulated to get the number of fibers lying in different angular directions. The orientation of fibers was studied to find out the disposition of fibers in different directions during creep.

Results and Discussion

Needle-punched Nonwoven

Varying Direction of Loading at Constant Load

The anisotropy in creep behavior of needle punched nonwoven geotextile at different level of loading is shown in Figures 1(a) to 1(c). It is to be noted that all the curves follow similar trend with a difference in instantaneous extension. The extension shows a gradual increase with time and finally stabilizing at a limiting extension value. Further, the comparison also shows a definite trend; wherein the sample which has a 0 degree inclination with machine direction shows maximum extension and maximum creep as well. The sample which has an angle of inclination of 90 degrees with the machine direction shows minimum instantaneous extension and creep. With increase in angle of inclination with machine direction, the samples show a decrease in creep values. The study of fiber orientation (using magnified images of fabric) shows that maximum fibers in the fabric are oriented in the angular range of 75-85 degrees. Least fibers are aligned in the machine direction and number of fibers in the fabric decreases with the angle made to machine direction. This result further supports the obtained result for creep; wherein maximum extension is observed in a direction with minimum number of fibers in the direction of loading and minimum creep extension is obtained for the sample having maximum number of fibers in the direction of loading. For other angles also the trend is same with the creep extension decreasing continuously with increase number of fibers in the direction of loading.

The creep of needle punched nonwoven fabrics follow linear relationships with logarithm of time and this is true for all the directions of load and for all the levels of loading. It can be observed from Table 2 that, for a particular level of load, the change in the direction of loading from 0 degree to 90 degree the rate of creep and the instantaneous extension reduce consistently. By this, we can infer that the rate of creep also depends on the orientation of fibers and is maximum in the machine direction and minimum in perpendicular direction.

Varying Load at a Particular Angle

When the amount of loading is increased in a particular

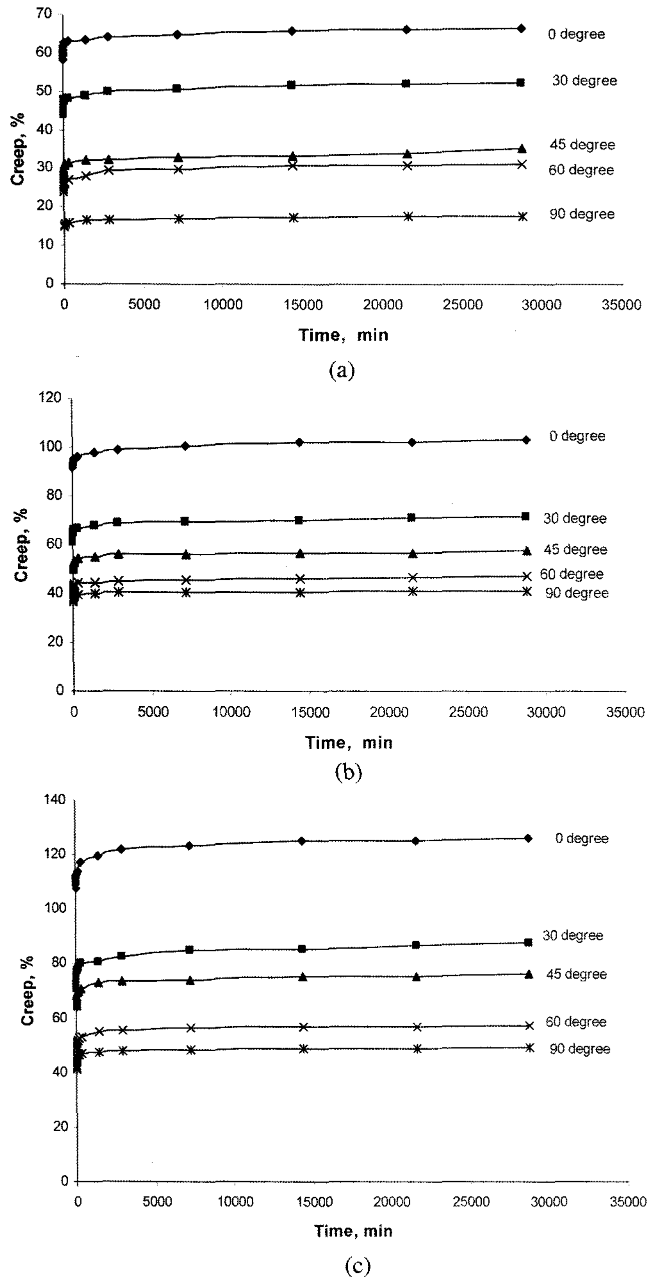

Figure 1. Anisotropy in creep behaviour of needle punched nonwoven geotextiles at (a) 30 %, (b) 45 %, (c) 60 % of breaking load.

direction the amount of creep increases in the fabric, which one can observed from Figures 1(a) to 1(c). The rate by which creep increases is also proportional to the level of loading, which can be observed form the slopes of the straight lines which we get from the graphs between log (time) vs creep, given in Table 2. The instantaneous extension also increases with the level of loading and it is true for all the direction of loading. As the load increases at any angle, the fibers aligned in that particular direction would share the load to the most.

Table 2. Relationship between logarithm of time (x) and creep (y)

Direction of loading (degree)	Level of load (%)	Linear relationships	R^2
0	30	y = 1.73x + 58.68	0.965
	45	y = 2.63x + 90.30	0.955
	60	y = 4.27x + 106.64	0.983
30	30	y = 1.69x + 43.90	0.987
	45	y = 2.28x + 61.08	0.994
	60	y = 3.78x + 70.07	0.990
45	30	y = 1.50x + 27.59	0.970
	45	y = 1.67x + 49.91	0.994
	60	y = 2.59x + 64.60	0.996
60	30	y = 1.21x + 23.31	0.970
	45	y = 1.28x + 40.91	0.968
	60	y = 2.05x + 48.47	0.996
90	30	y = 0.65x + 14.56	0.963
	45	y = 0.95x + 36.95	0.985
	60	y = 1.59x + 42.46	0.923

The creep increases because the higher load would definitely increase the fiber-to-fiber slippage and also exert higher force to the individual fibers which result in higher creep of individual fibers also.

Thermobonded Spun-laid Nonwoven

Varying Direction of Loading at Constant Load

Figures 2(a)-(c) show the anisotropy in creep behavior of thermobonded spun-laid nonwoven geotextile at different level of loading. It can be observed that all the curves follow similar trend with a difference in instantaneous extension. The extension shows a gradual increase with time and finally stabilizing at a limiting extension value. But, the analysis of the results shows that the creep of the thermobonded spun-laid nonwovens does not follow the logarithm relationship, as in case of needle-punched nonwovens. It is also clear from the Figures 2(a)-(c) that the instantaneous extension and the creep are different for different samples. Comparisons show that the sample cut perpendicular to machine direction (90 degree) shows a minimum of extension followed by the sample cut along the machine direction (0 degree). The maximum extension is observed in the case of 45 and 30 degree angle. In fact, for a 60 % load the sample shows a break in 5 days. The study of fiber orientation (using magnified images of fabric) shows that fibers are laid randomly but parallel set of fibers appear crossing each other. Large proportion of the fibers appear along the machine direction as well as perpendicular to the machine direction. This is also in accordance with the results obtained in the creep experiment which show minimum

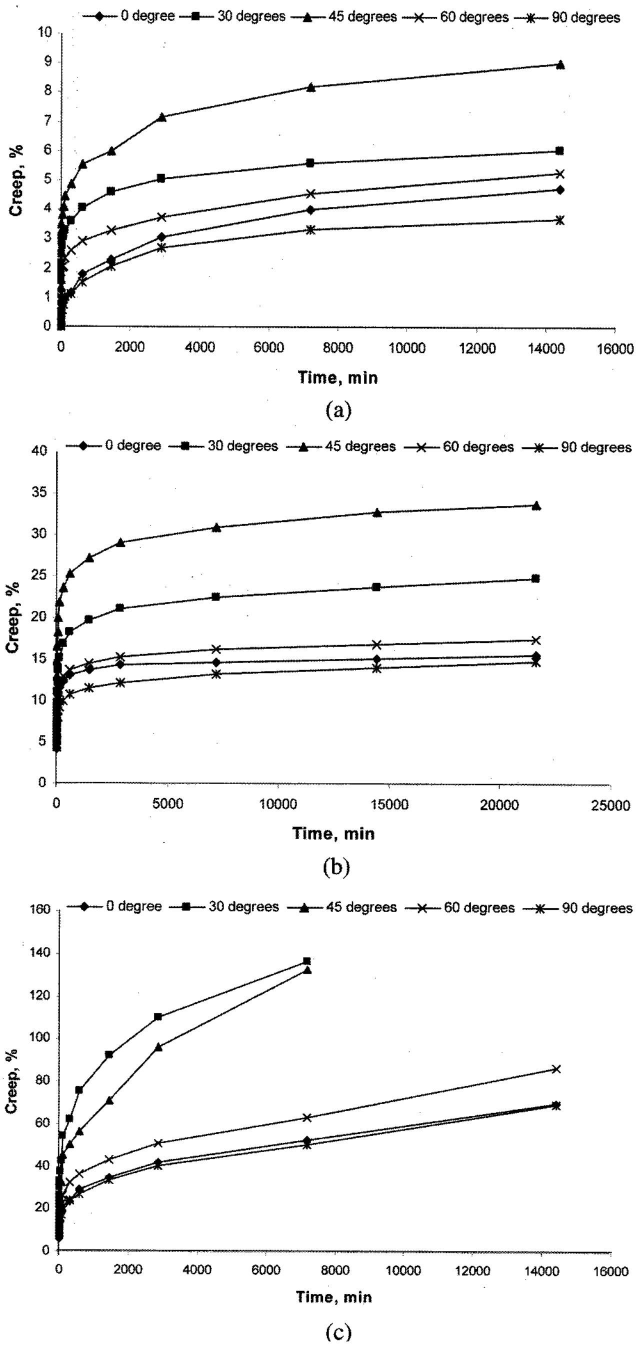

Figure 2. Anisotropy in creep behaviour of thermobonded spun-laid nonwoven geotextiles at (a) 30 %, (b) 45 %, (c) 60 % of breaking load.

creep in the direction perpendicular to machine direction followed by creep along machine direction. Maximum extension is observed in a direction with minimum number of fibers in the direction of loading. There were breakages at 60 % of load in the case of 30 degree and 45 degree angle in around 5 days time.

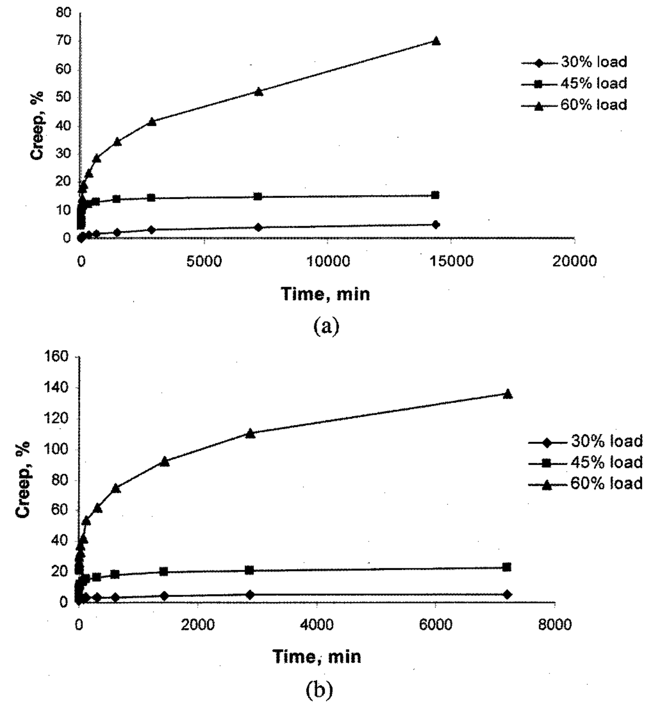

Figure 3. Creep behaviour of thermobonded spun-laid nonwoven geotextiles at different level of loads; (a) machine direction, (b) 30 degree with machine direction.

Varying Load at a Particular Angle

The typical creep behavior of thermobonded spun-laid nonwovens with different level of loads at 0 degree and 30 degree with the machine direction is shown in Figures 3(a) and 3(b) respectively. The creep behavior with other direction follows exactly the similar trend. From the Figures 3(a) and 3(b) it is clear that as the level of load increases, the amount of creep increases with the time, but there is an abrupt increase at 60 % load compared to 45 %. Loading at 30 degree angle (Figure 3b) the samples were plotted up to 5 days time because at 60 % load there were failures of whole structure for 30 degree and 45 degree directions. The reason for this has been discussed earlier.

Conclusions

The creep test of the nonwoven fabric samples show that the amount of time dependent extension depends on the direction and amount of loading and the structure of nonwoven the fabrics. The time dependent extension (creep) for the nonwoven fabric increases with the increase in amount of load. The more creep and more initial extension are observed for needle punched nonwoven fabric than thermobonded nonwoven fabric. The creep behavior of needle-punched nonwoven shows a logarithmic relationship with time, but the thermobonded spun-laid nonwoven fabric does not show such logarithmic relationship.

For a particular fabric the creep is dependent on the fiber arrangement and is minimum in the direction in which the proportion of fiber is maximum and visa versa. For example, in case of the needle punched nonwoven fabric the proportion of fiber is maximum in direction perpendicular to the machine direction and the initial extension as well the creep is minimum in that direction. But in case of the thermobonded nonwoven fabrics the fiber proportion is more in the machine direction and as well in the direction perpendicular to the machine direction and minimum in the range of 30-45 degree to the machine direction. So, the results also follow the same trend, i.e., the creep and initial extension is minimum in the machine and perpendicular to the machine direction and maximum in the 30 and 45 to the machine direction. The creep and initial extension is found to be intermediate in the 60 degree angle to the machine direction.

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