LOWLAND TECHNOLOGY INTERNATIONAL Vol. 4, No.1, 1-12, June 2002
International Association of Lowland Technology (IALT), ISSN 1344-9656

INFLUENCE FACTORS ON THE LABORATORY TESTING OF GEOTEXTILES UNDER CONTROLLED ENVIRONMENT

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ABSTRACT: In order to investigate the influence factors affecting index and engineering properties of geotextiles under controlled environments, different tests were conducted using both heat-bonded nonwoven and needle-punched nonwoven geotextiles, namely: apparent opening size (AOS), wide-width tensile strength, permittivity, transmissivity, and puncture resistance. The effect of humidity on the pore size of the samples was also investigated. To check whether the clamping system has an effect on the strength of geotextiles, over 240 tests were conducted. The presence of air bubbles in water and its effect on the permittivity and transmissivity of geotextiles were also verified. Also investigated were the effects of higher strain rate and displacement rate on the tensile strength and puncture resistance, respectively. The results indicate that decreasing humidity slightly increased the AOS; higher strain rate and the use of hydraulic clamp increased the wide-width tensile strength; using de-aired water largely improved the permittivity and transmissivity; and increasing the strain rate decreased the puncture resistance. The effects of humidity and oxygen content were more pronounced and obvious in the case of needle-punched geotextile compared to heat-bonded nonwoven geotextile.

INTRODUCTION

In recent years, both woven and nonwoven geotextiles, have been used extensively in civil engineering applications. In order to quantify the performance properties of the selected geotextile, physical, mechanical and hydraulic tests were performed under controlled conditions in the laboratory. Mechanical property tests included the following: narrow strip tensile, wide-width tensile, trapezoidal tear, burst strength, and puncture strength. Physical property tests consisted of mass per unit area, nominal thickness and apparent opening size (AOS). Hydraulic property tests included permittivity and transmissivity tests. The objective of this paper is to investigate the factors affecting laboratory testing of geotextiles using two types of non-woven geotextiles, namely: needle-punched (NP-TS500, NP-TS700 and NP-TS800) and heat-bonded geotextiles (HB-3267 and HB-3407). To investigate the factors affecting laboratory testing of geotextiles, several tests were carried out under various conditions. The effect of humidity was investigated on the apparent opening size (AOS) test conducted using dry sieving method. The results of using different strain rate and clamping system on wide-width tensile strip test was also evaluated. The data of permittivity and transmissivity tests performed using tap and de-aired water were compared. The effect of strain rate was also evaluated on puncture resistance and tensile strength tests.

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Note: Discussion on this paper is open until December 25, 2002.

NONWOVEN GEOTEXTILES

Nonwoven geotextiles are generally made through spunbonding process consisting of four steps: fiber preparation, web formation, web bonding and winding into rolls. Melted polymer is first fed into an extruder and forced through a spinneret. The fibers are then stretched after cooling. The web is made by continuously placing fibers to a thickness slightly larger than the final product onto a moving conveyor belt. The fibers form a loose web, which are then, most commonly, bonded together by either mechanical or thermal bonding.

Needle-punching is the mechanical process used to bond nonwoven geotextiles. In the process, the web is passed under a needle board, which is made up of thousands of barbed needles. During this process, outside fibers are dragged down inside the web, causing them to interlace with other fibers. A thick geotextile, where fibers are free to move over each other is created. The bonding of the geotextile depends on the mechanical entanglement and fiber-to-fiber friction.

Thermal bonding, also known as "heat-bonding" or "melt-bonding", is a bonding process, which actually melts the web together at fiber cross-over points. In this process, the web is passed through a source of heat, such as pressurized steam or hot air, which causes fusion at fiber cross-over points. Strong, flexible bonds may be formed at cross-over points, because only the outer shell melts and bonds to other heterofilaments and homofilaments. The degree of fusion, line speed, and the engraved pattern on the roll affect the finished geotextile pore-size distribution. The pore-size distribution will also depend on the fiber type and the density of fibers in the geotextile.

LABORATORY TESTING OF GEOTEXTILES

Apparent Opening Size (AOS) Test

The AOS is defined as the size of the largest particle that would effectively pass through the geotextile. In the test, glass bead fractions are sieved through a geotextile to determine the diameter of the glass beads where 95% by weight is retained on the geotextile

Gerry and Raymond (1983) concluded that the ability of a particle to pass through a specimen is significantly affected by electrostatic phenomenon. Static charge imbalance may arise between the glass bead particle and fabric polymer, or the glass bead particle and polymer with moisture. Faure et al. (1990) concluded that static effects are more pronounced in dry sieving, preventing the passage of smaller particles. Therefore, larger values are generally measured for the finer pores in a geotextile.

Bhatia et al. (1995) concluded that one of the primary difficulties with the dry sieving test is electrostatic effect between glass beads, and between glass beads and the geotextile. Glass beads may stick to fibers making the pore effectively smaller, or the glass beads may agglomerate to create one large glass bead agglomerate, which will not pass. The glass bead agglomerate may be broken up after sieving successive glass bead fractions and eventually pass through the geotextile, affecting the results of another glass bead fraction.

The AOS or O_{95} was determined by using the Standard Test Method for Determining the Apparent Opening Size of a Geotextile (ASTM D4751 1994). Five specimens were cut along a diagonal line on the geotextile sample with each specimen being cut to fit the appropriate sieve pan. After taking its weight the specimens were submerged in distilled water for one hour at the standard atmosphere for testing. The specimens and glass beads were dried in an oven at 30^0C until the change in mass between two successive weighings made at intervals of not less than 2 hours does not exceed 0.1% of the mass of the specimen and the glass beads.

The dry specimen was secured to the sieve frame and 50 g of one size of glass beads was placed on its center. The cover and pan were then put in place and then placed in the shaker. The mechanical sieve shaker imparts a vertical or lateral motion to the sieve causing the particles to bounce and turn so as to present different orientations to the sieving surface. After the sieve was shaken for 10 min the weight of the glass beads that passed through the geotextile were taken and recorded. The sieving process was repeated using successively smaller bead size fraction until the weight of the beads passing through the specimen is 5% or less. For each size of beads tested, the nearest percentage of the beads passing through the specimen was computed using:

$$B = 100P / T \tag{1}$$

where B is percentage of beads passing through the specimen, P is mass of glass beads in the pan in grams and T is total mass of glass beads used in grams.

Wide-Width Tensile Test

Numerous tests have been developed for determining the stress-strain characteristics of geotextiles. The most widely used are the grab tensile and the strip tensile test. Both tests provide an index to the modulus and the strength of the fabric. However, because of the difference in boundary conditions between laboratory and field, neither test provides properties representative of the field conditions. The strip tensile method measures the load-elongation relationship of a geotextile specimen with a narrow width clamped between two jaws. It is a test as simple as the grab test, but there are inherent drawbacks such as the contraction of the specimen width and the slippage of the specimen at the jaw. These drawbacks have been improved in the wide-width method. Shrestha and Bell (1982) have investigated the factors affecting wide-width strip tensile test and concluded as follows:

1) The ultimate strengths of geotextiles measured in strip tensile tests are not significantly affected by the specimen size. However, the failure strains of the laboratory specimens are affected significantly by specimen width and gauge length.

2) The load-strain relationships measured for geotextiles may vary considerably with specimen width and gauge length. Woven geotextiles are mostly influenced by aspect ratios greater than 4.0 and specimen gauge length of less than 50 mm. Nonwoven geotextiles are most influenced by aspect ratios less than 2.0 and specimen widths less than 100 mm.

3) A wide strip tensile test utilizing specimens 200 mm wide and 100 mm gauge length is recommended for routine laboratory testing. At this specimen size, plane-strain loading conditions on geotextiles can be approximated without use of a restraining device to limit lateral contraction of specimens during strip tensile test.

4) The laboratory measurements of tensile properties are not significantly different at strain rates of 1.25 to 12.5% per minute. A strain rate of 10% per minute is recommended for routine strip tensile tests.

The ASTM D4595 (1994) described as the Standard Test Method for Tensile Properties of Geotextile by the Wide-Width Strip Method was followed in the testing. Specimens were cut 100 mm wide by 200 mm long along a diagonal line on the sample in both machine and cross machine directions. The specimen thickness was measured at its four corners. The specimens were brought to moisture equilibrium in the atmosphere for testing geotextiles. Equilibrium is considered to have been reached when the increase in mass of the specimen in successive weighings made at intervals of not less than 2 hours does not exceed 0.1% of the specimen mass. The specimen was then mounted centrally in the clamp. To verify the effects of the clamping system on the test, two kinds of clamps were used: hydraulic clamp (Fig. 1) and mechanical clamp (Fig. 2). The specimen was pulled in tension until the specimen ruptures. Data was recorded using a data logger. The tensile strength was calculated by:

$$\alpha_f = F_f / W_s \tag{2}$$

where α_f is tensile strength in N/m of width, F_f is observed breaking force in N and W_s is specified specimen width in m. The elongation of the specimen was computed by:

$$\varepsilon_p = (\Delta L \times 100) / L_g \tag{3}$$

where ε_p is elongation in percent, ΔL is unit change in length from a zero force to the corresponding measured force in m and L_g is initial nominal gage length in m.

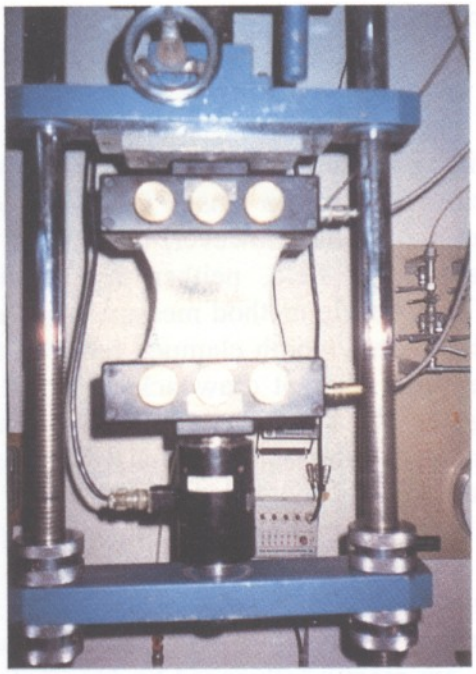

Fig. 1 Tensile testing machine by using the hydraulic clamp

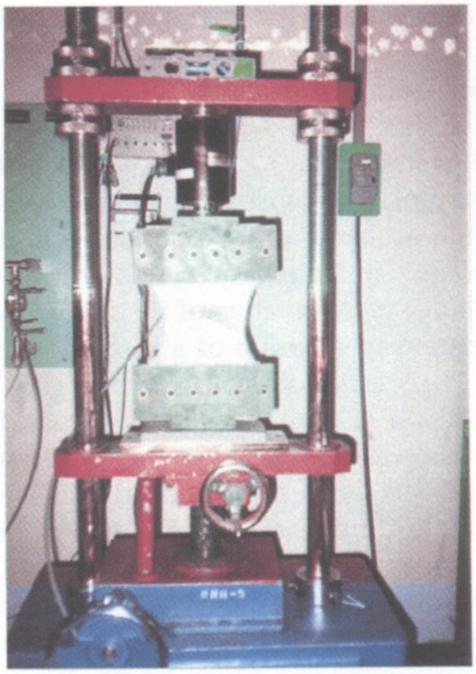

Fig. 2 Tensile testing machine by using the mechanical clamp

Constant Head Hydraulic Permittivity Test

The permittivity test evaluates flow characteristics of geotextiles in the cross plane direction. Permittivity is an indicator of the quantity of water that can pass through a geotextile in an isolated condition independent of the thickness of the geotextile.

Halse et al. (1988) have investigated the effect of dissolved oxygen (and bubbles) on the measured permittivity of geotextiles and the results of these tests can be summarized as follows:

1) Vacuum de-airing produces water that will yield the correct upper limiting value of the permittivity of a geotextile.

2) Visual air bubbles in the water will reduce the measured permittivity to unrealistically low values.

3) The dissolved oxygen content (DOC) can rise above the stipulated 6 ppm and give essentially the correct permittivity (within 15%) as long as bubbles are not present and the measurements are not carried on for too long period (less than an hour).

The permittivity was obtained following the procedure from ASTM D4491 (1994) or the Standard Test Method for Water Permeability of Geotextiles by Permittivity. Figure 3 shows the test apparatus. It consists of upper and lower units fastened together. The test specimen is positioned in the bottom of the upper unit. There is a standard pipe for measuring the constant head value. The rotating discharge pipe allows adjustment of the head of water at the bottom of the specimen. With the specimen in place, the bleed valve was opened and the system was back filled through the standpipe until water flows from it. The apparatus was then filled with water until the water level reaches the overflow. With water flowing into the system through the water inlet, the discharge pipe was adjusted along with the rate of water flowing into the apparatus to obtain 0.05 m head of water on the geotextile.

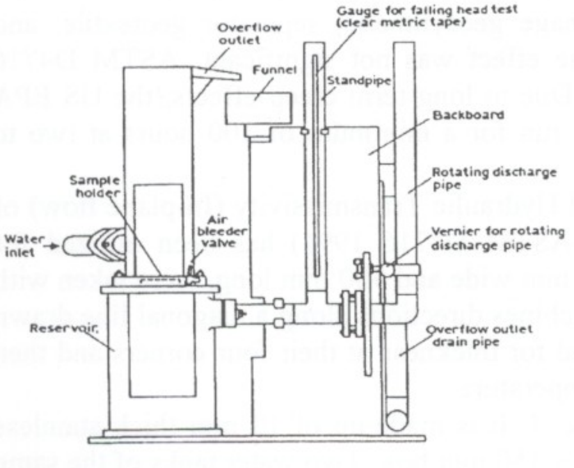

Fig. 3 Permittivity test apparatus

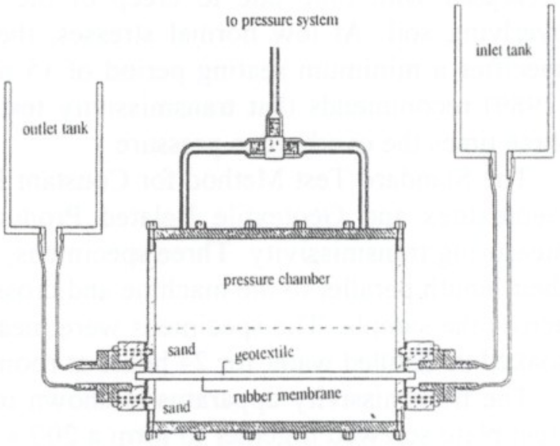

Fig. 4 Transmissivity test apparatus

The time it takes to collect 0.0005 m^3 of water from the discharge pipe while holding the head at 0.05 m was recorded. The permittivity of each specimen can be computed by:

$$\psi = QR_t / h \cdot A \cdot t \tag{4}$$

where ψ is permittivity in s^{-1}, Q is quantity of flow in m^3, h is head of the water on the specimen in m, A is cross-sectional area of the specimen in m^2, t is time for flow in seconds and R_t is temperature correction factor given as:

$$R_t = V_t / V_{20} \tag{5}$$

where V_t is water viscosity at test temperature and V_{20} is water viscosity at 20°C.

Constant Head Hydraulic Transmissivity Test

The inplane flow within the geosynthetic is the critical factor for drainage applications. The hydraulic transmissivity (θ) is commonly used to describe the inplane permeability defined as:

$$\theta = k \cdot d \tag{6}$$

where k is hydraulic conductivity and d is thickness of geosynthetic. When the flow is laminar, the transmissivity is generally constant at different hydraulic gradients. Since the flow has been found to be turbulent for geonets and geocomposites (Williams et al. 1984; Cancelli et al. 1987), the flow rate per unit width is often used instead of the transmissivity and is given as:

$$q/W = \theta \cdot I \tag{7}$$

where q is flow rate, W is width of the specimen and I is hydraulic gradient.

Empirical relationships have been developed to estimate the transmissivity of geotextiles (Raumann 1982; Lonescu and Kellner 1982; Gourc et al. 1982; Ling et al. 1990). Previous studies (Hwu et al. 1990; Slocumb et al. 1986; Koerner et al. 1986; Cancelli et al. 1987; Smith and Kraemer, 1987) have investigated the effects of time on the flow rate. The flow rate decreased with time due to creep of the drainage geosynthetic, separator geotextile, and overlying soil. At low normal stresses, the time effect was not significant. ASTM D4716 specifies a minimum seating period of 15 min. Due to long-term creep effects, the US EPA (1989) recommends that transmissivity tests be run for a minimum of 100 hours at two to three times the overburden pressure.

The Standard Test Method for Constant Head Hydraulic Transmissivity (In-plane flow) of Geotextiles and Geotextile Related Products (ASTM D4716 1994) has been utilized for measuring transmissivity. Three specimens, 100 mm wide and 300 mm long, were taken with their length parallel to the machine and cross machines directions along a diagonal line drawn across the sample. The specimens were measured for thickness at their four corners and then soaked in distilled water for 24 hours at room temperature.

The transmissivity apparatus is shown in Fig. 4. It is made-up of 10 mm thick stainless steel plate screwed together to form a 200 x 250 x 150 mm box. Two water tanks of the same size were connected to the opposite ends of the box. The inlet tank provides constant head water supply and is adjustable so as to vary its elevation and, thus, its hydraulic gradient. The outer tank is used to collect water and is weir-shaped.

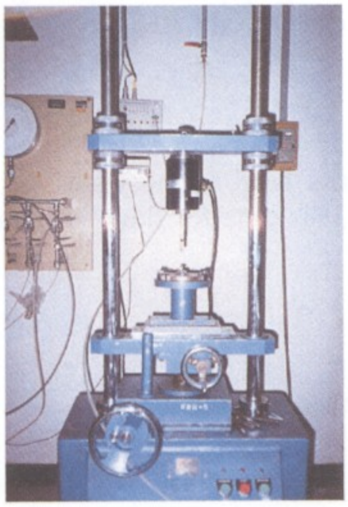

Fig. 5 Puncture testing machine

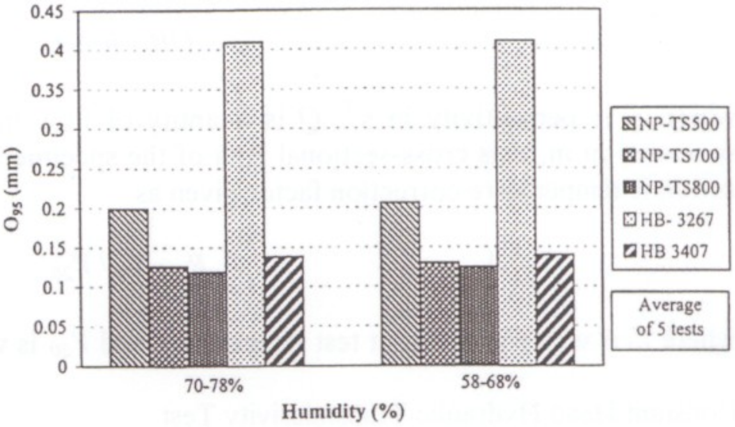

Fig. 6 Effect of humidity on O_{95} of nonwoven geotextiles

After soaking, the specimen was inserted in a rubber membrane before it was assembled in the box between two sand layers. Pressure was applied through rubber balloons placed above the sand and connected to the pressure system. A normal compression stress ranging from 25 to 200 kPa was applied and allowed to seat for 15 minutes. The inlet tank was then filled with water and allowed to flow through the specimen and into the outlet tank until a steady condition was attained and hydraulic gradient was maintained. Once uniform flow through the specimen was observed, the time it took for 0.0005 m^3 of water was allowed to pass through the specimen was taken. If this time exceeded 15 minutes, the quantity of flow collected at 15 minutes was used in the calculation of hydraulic transmissivity. The flow reading was repeated for at least three times for each hydraulic gradient selected. The transmissivity of the specimen was computed as:

$$\theta = Q \cdot L \,/\, W \cdot H \tag{8}$$

where θ is hydraulic transmissivity in m^2/s, Q is average quantity of fluid discharged per unit time in m^3/s, L is length of the specimen in m, W is width of the specimen in m and H is difference in total head across the specimen in m.

Puncture Resistance Test

In the design of geosynthetic materials, focus is generally placed on the primary function that the material will be asked to serve. Whatever the required set of properties, however, the geosynthetic must be capable of being transported, installed and covered in its final position without failure. Of the various survivability guides that are available, all address some form of puncture or impact strength that the geosynthetic must be capable of sustaining.

Puncture resistance is the inherent resistance of the test specimen to failure by a penetrating or puncturing object. Koerner et al. (1986) conducted puncture tests and concluded that increasing the mass per unit area of a geotextile increases its puncture resistance.

The Standard Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products (ASTM D4833 1994) was used to test the geotextile. Specimens were cut along a diagonal line on the laboratory sample with a minimum diameter of 100 mm to facilitate clamping. The specimens were brought to moisture equilibrium with the atmosphere. Equilibrium is achieved when the increase in the mass of the specimen in successive weighing made at intervals of not less than 2 hours does not exceed 0.1% of the mass of the specimen.

A tensile/compression testing machine of constant rate of extension was used and connected to the data logger. Figure 5 shows the test apparatus. It consists of a ring clamp attachment, a concentric plate with an open internal diameter of 45 mm, which is capable of clamping the test specimen without slippage and a flat-end solid steel rod 8 mm in diameter with a 45^0 chamfered edge in contact with the test specimen's surface. The specimen was centered and secured between the holding plates ensuring that it extends to or beyond the outer edges of the clamping plates. The puncture rod was then lowered to the sample at a machine speed of 50, 150 and 320 mm/min until it completely punctured the specimen.

FACTORS AFFECTING TESTING

Effect of Humidity on O_{95}

The effect of humidity on O_{95} of nonwoven geotextiles is presented in Fig. 6. The O_{95} values of needle-punched nonwoven geotextile, NP-TS500, NP-TS700 and NP-TS800 increased by 3.5%, 3.2% and 5.0%, respectively, due to a decrease in humidity from 70-78% to 58-68%. On heat-bonded nonwoven geotextile, HB-3267 and HB-3407, the values of O_{95} merely increased by 0.24% and 1.44%, respectively, when the humidity decreased from 68-

76% to 58-67%. The results indicate that a 10% change in humidity will only have a slight effect on the AOS of nonwoven geotextiles. The needle-punched geotextile was affected more than the heat-bonded geotextile because the structure of the former easily traps the beads within the geotextile.

Effect of Clamping System on Tensile Strength

Figure 7 shows the effect of clamping system on the ultimate wide-width tensile strength in the machine direction. The results from the use of hydraulic clamp yielded slightly higher values than the corresponding values using the mechanical clamp at a strain rate of 10 %/min because the stress distribution of the geotextile using hydraulic clamps system is more uniform than the mechanical clamping. Moreover, the slippage at the clamps has been eliminated using the hydraulic clamping system. The ultimate strength of needle-punched geotextiles increased by 12.5%, 19.9% and 7.6%, respectively, for NP-TS500, NP-TS700 and NP-TS800. For heat-bonded geotextile, HB-3267 and HB-3407, the strength increased by 1.4% and 8.0%, respectively. The results in the cross-machine direction also indicate increasing ultimate tensile strength with increased strain rate.

Effect of Strain Rate on Tensile Strength

The increasing strain rate from 10 %/min to 40 %/min resulted to a slight increase in strength as shown in Fig. 8. The strength of needle-punched nonwoven geotextiles, NP-TS500, NP-TS700 and NP-TS800 in the machine direction increased by 7.0%, 0.6% and 3.2%, respectively. For heat-bonded nonwoven geotextile, HB-3267 and HB-3407, the strength in the machine direction increased by 13.3% and 8.4%, respectively, because of the more progressive failure in the low strain rate tensile test. The effect of strain rate on the tensile strength of the geotextile in the cross-machine direction is similar to the results in machine direction in a way that the strength generally increased with increasing strain rate.

The effect of strain rate on the strain of nonwoven geotextile in the machine direction are given in Fig. 9. For needle-punched nonwoven geotextile, NP-TS500, NP-TS700 and NP-TS800, the strain decreased by as much as 15.1%, 7.6% and 2.4%, respectively, due to increase of the ultimate tensile strength with increasing strain rate. Similarly, the ultimate strain of heat-bonded nonwoven geotextile, HB-3267 and HB-3407, also reduced by as much as 9.1% and 25.5%, respectively. The ultimate strain magnitudes in the cross-machine direction also decreased with increasing strain.

Effect of Displacement Rate on Puncture Resistance

The effects of displacement rate on puncture resistance are illustrated in Figs. 10 and 11. The decrease in displacement rate from 320 mm/min to 160 mm/min increased the puncture resistance. The needle-punched nonwoven geotextiles, NP-TS500, NP-TS700 and NP-TS800, increased its puncture resistance by as much as 15.3%, 18.2% and 29.7%, respectively. For heat-bonded nonwoven geotextile, HB-3267 and HB-3407, the value of puncture resistance increased by 21.2% and 21.5%, respectively.

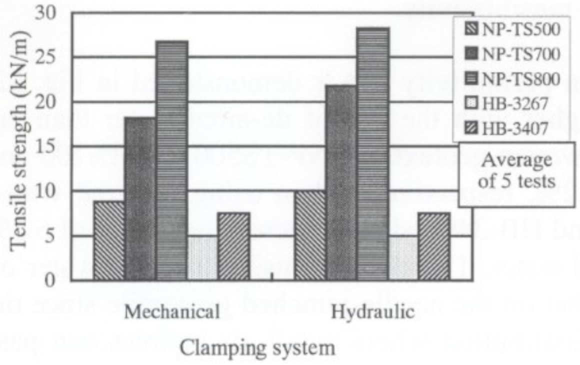

Fig. 7 Effect of clamping system on ultimate wide-width tensile strength for nonwoven geotextiles in machine direction of strain rate at 10 mm/min

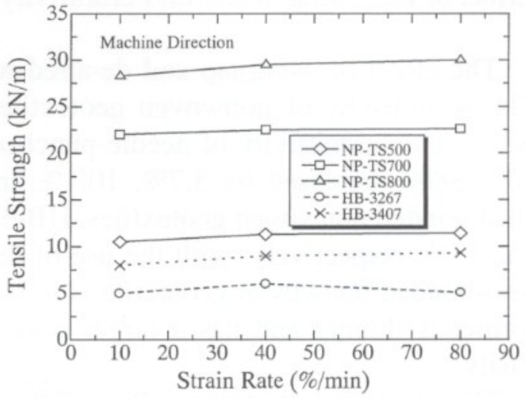

Fig. 8 Effect of strain rate on ultimate wide-width tensile strength for nonwoven geotextiles tested in machine direction

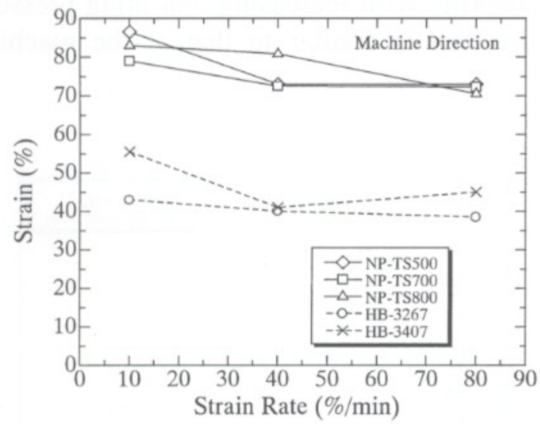

Fig. 9 Effect of strain rate on ultimate strain for nonwoven geotextiles tested in machine direction

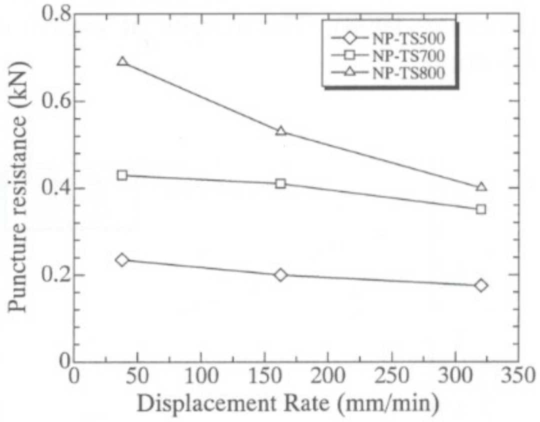

Fig. 10 Puncture resistance versus displacement rate of needle-punched nonwoven geotextile

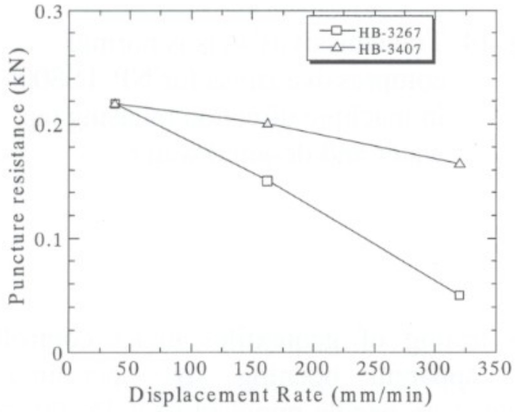

Fig. 11 Puncture resistance versus displacement rate of heat-bonded geotextile

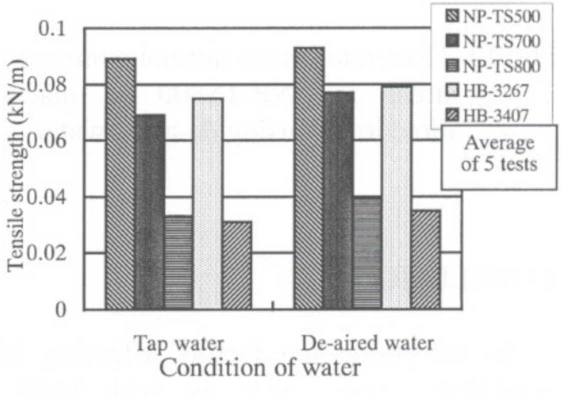

Fig. 12 Effect of tap water and de-aired water on the permittivity of nonwoven geotextile

Effect of De-Airing Water on Permittivity and Transmissivity

The effect of using tap and de-aired water in permittivity test is demonstrated in Fig. 12. The permittivity of nonwoven geotextile is higher with the use of de-aired water than tap water. The permittivity of needle-punched nonwoven geotextiles, NP-TS500, NP-TS700 and NP-TS800 increased by 5.7%, 10.1% and 21.2%, respectively when using de-aired water. Heat bonded nonwoven geotextiles, HB-3267 and HB-3407 yielded increasing values of 5.3% and 13%, respectively, with the use of de-aired water. The effect of using de-aired water on heat-bonded nonwoven geotextile is less than that on the needle-punched geotextile since the former is thinner and has a larger pore size distribution where small air bubbles can pass easily.

The transmissivity test results at different hydraulic gradients are plotted in Fig. 13. Higher value of flow rate was observed when using higher hydraulic gradient. The effect of tap and de-aired water on the transmissivity of NP-TS800 are shown in Fig. 14. At 0.2 hydraulic gradient, the transmissivity of NP-TS800 in the machine direction yielded higher values when using de-aired water by as much as 4.9% to 14.6% at normal compressive stress ranging from 25 kPa to 200 kPa. The decreasing transmissivity was observed at higher values of normal stresses because of the decreasing thickness of geotextile with increasing confining pressure (Koerner 1998). The results at cross-machine direction is similar to that at the machine direction.

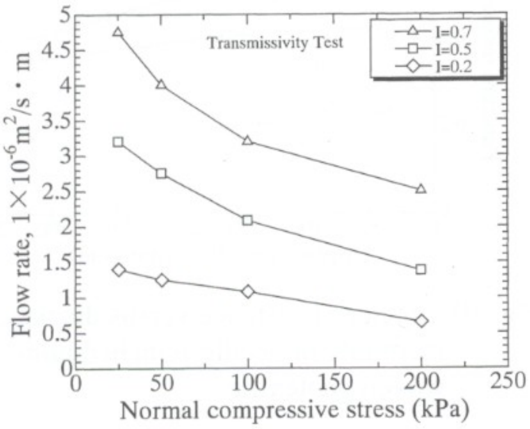

Fig. 13 Flow rate versus normal compressive stress for NP-TS800 in machine direction by using de-aired water

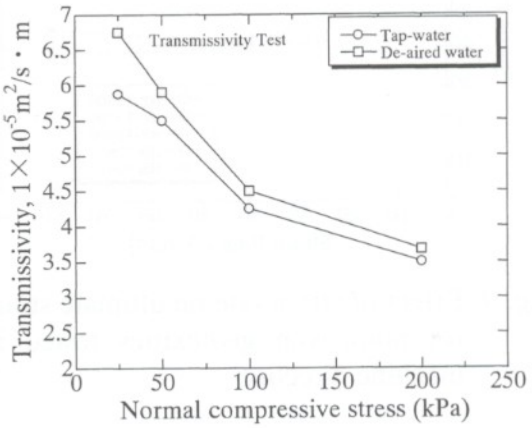

Fig. 14 Transmissivity versus normal compressive stress for NP-TS800 in machine direction by using tap water and de-aired water

CONCLUSION

To determine the factors affecting laboratory testing of geotextiles under controlled conditions, tests such as wide-width tensile, apparent opening size, permittivity, transmissivity and puncture resistance were conducted on needle-punched (NP-TS500, NP-TS700 and NP-TS800) and heat-bonded (HB-3267 and HB-3407) nonwoven geotextiles. A 10% increase in the humidity during apparent opening size tests slightly increased the O_{95} of the geotextiles. A total of 240 samples were tested to investigate how the clamping system affected the geotextile's tensile strength in both the machine and cross-machine directions. The use of hydraulic clamps gave higher values of tensile strength when compared to the values obtained using mechanical clamps. The advantages of using de-aired water over tap water in permittivity and transmissivity tests were also verified. The use of de-aired water over tap water resulted to higher values in both permittivity and transmissivity tests. The effect of using a faster strain rate on the tensile strength in both directions and the puncture resistance of a geotextile were also investigated. A change in strain rate from 10 %/min to 80 %/min resulted to a slight increase in the ultimate tensile strength and a decrease in the strain of the geotextiles. Moreover, the effects of humidity on AOS, and de-airing water of water on permittivity and transmissivity are much profound and obvious in the case of needle-punched than on heat-bonded nonwoven geotextiles.

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