Study the Effect of Test Speed and Fabric Weight on Puncture Behavior of Polyester Needlepunched Nonwoven Geotextiles

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ABSTRACT

In this research, the effects of speed and weight on needlepunched nonwoven geotextiles subjected to CBR and Puncture tests were investigated. Polyester nonwoven fabrics with different weights (460, 715, 970 and 1070 g/m^2) were prepared. The CBR test (ASTM D 6241) was conducted with five speeds, 25, 50, 75, 100 and 125 mm/min on geotextile layers, while the Puncture test (ASTM D 4833) was carried out at a standard speed of 300 mm/min on the same fabrics. Based on the load-elongation curves of these two tests, different puncture parameters, including puncture resistance (puncture force at failure), elongation at maximum force and puncture energy, were measured and statistically analyzed using ANOVA and multiple-range test methods.

The results of the CBR tests indicate that the fabric weight significantly influenced the puncture resistance as well as the puncture energy and elongation while speed only affected the fabric puncture resistance and puncture energy.

On the other hand, in the Puncture test, the fabric weight influenced all measured parameters.

Keywords: Nonwoven Geotextile, Puncture Resistance, Polyester Fibers, Layer Weight, CBR Test, Puncture Test, Test Speed.

INTRODUCTION

Needlepunched nonwoven fabrics are the most common fabrics used as geotextiles and can perform four main functions: reinforcement, filtration, drainage and separation.

Geotextiles are traditionally subjected to perpendicular forces to their plane because of the fabric's subgrade surface irregularities. Geotextiles are used as a support material and this is not just related to usage in roadways. Fabric survivability is critical in all types of applications and without it the best of designs are not trust worthy.

Sharp stones, tree stumps, roots and other items either on the ground surface placed beneath the geotextile or above it could puncture through the geotextile during backfilling or when the traffic loads are imposed [1].

So, the geotextile is subjected to concentrated forces perpendicular to its plane while the fabric is already under in-plane tensions due to subgrade surface irregularities [2]. Thus, the rate of loading on the geotextiles layer is a concern.

Ghosh [2] studied the puncture resistance of geotextiles under a uniform radial pre-strain. His test results showed that the lower puncture failure strain is obtained with an increase of pre-straining of the sample in all woven and nonwoven geotextiles [2].

Bergardo, et al. [3], studied the effect of axisymmetric loading, puncture speed and fabric weight on the increase of the bearing capacity of a soil-geotextile system with different types of geotextiles. In this investigation, the puncture behavior of needlepunched nonwoven geotextile fabrics was evaluated under the conditions of low speed and fabric weight. The results indicated that by increasing the elongation rate in the range of 20-80 mm/min, the puncture resistance partially increases.

Koerners [4] studied the puncture resistance of PET and PP needlepunched nonwoven geotextiles using three different probe shape types, according to ASTM D4833, D5495 and D6241. The result showed that, with the increase of fabric weight, the puncture resistance of all nonwoven geotextiles increased and the result values for the CBR test was higher than the Pin and Pyramid (probe shape types) test methods. The results showed that the puncture resistance of needlepunched nonwoven geotextiles had measurably increased by changing the fiber's base resin from PET to PP at an equivalent mass per unit area. It was also concluded that needlepunched nonwoven fabrics used for protection (or cushioning) of geomembranes was better when geotextiles were made from PP fibers than those made from PET fibers.

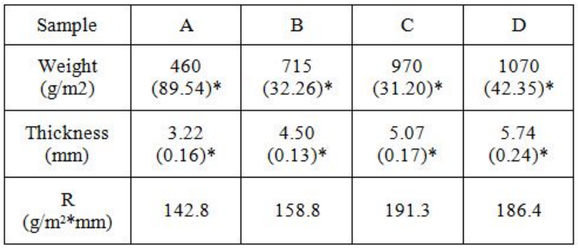
It should be noted that in a previous research work [3], the puncture behavior of the geotextiles was investigated at a lower speed range. Thus, the aim of the current study was to investigate the influence of the geotextile weight and speed on its puncture behavior and puncture resistance.

EXPERIMENTS

Material

In this work, polyester needlepunched nonwoven geotextiles were prepared. The range of the fiber length was 95-100 mm and the fineness of the fibers was 12 denier. The geotextiles specifications are shown in *Table I.*

TABLE I. Geotextiles with different unit weight.



Sample	A	B	C	D
Weight (g/m2)	460 (89.54)*	715 (32.26)*	970 (31.20)*	1070 (42.35)*
Thickness (mm)	3.22 (0.16)*	4.50 (0.13)*	5.07 (0.17)*	5.74 (0.24)*
R (g/m^2*mm)	142.8	158.8	191.3	186.4

*(The value in parenthesis is the related Standard Deviation).

It is noted that R values in *Table I* are calculated as the ratio of weight to thickness. This ratio is an indicator of the number of fibers in the layers' cross-section. As is shown, there is an increasing trend from layer A to C, but layer D represents fewer fibers than layer C.

CBR and Puncture Tests

In order to investigate the puncture behavior of the geotextiles, CBR and Puncture tests were conducted.

CBR, which stands for California Bearing Ratio, is a test for measuring geosynthetics puncture resistance. The CBR test was conducted according to ASTM D6241 [5]. A clamp and a cylindrical plunger were designed and constructed, which are shown in *Figure 1a* and *1b* respectively. The clamp consisted of two circular plates with inner diameters of 150 mm. The geotextile specimen was held and secured between theses plates by eight screws. The cylindrical plunger diameter was 50 mm with a flat end. The plunger edge was a bit round with a radius of 2.5 ± 0.5 mm.

The plunger and the clamp were installed on a Zwick Universal Testing Machine which ran at a constant rate of elongation (CRE).

The clamp was put beneath the plunger and centered. Tests were carried out with different speeds, 25, 50, 75, 100 and 125 mm/min, while the standard test speed was 50 mm/min. Then the plunger came down and punched the specimen secured in the clamp. Simultaneously, the PC registered the load as well as the displacement and puncture energy.

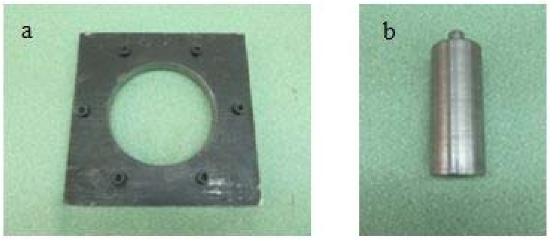


FIGURE 1. (a) CBR test clamp. (b) CBR test plunger.

Based on the load-displacement curves of the CBR test, there were different puncture parameters including:

F (KN): Puncture resistance (Puncture force at failure)

d (mm): Elongation at maximum puncture force (Displacement of the plunger from the beginning of the test to end of it)

Puncture energy at F-Max (J): Puncture energy (the area under the force-displacement curve) was measured. Five specimens were tested for each layer in each speed which was a total of 25 samples for each weight. Results are shown in *Table II*.

TABLE II. CBR test results.

Sample	Test Speed (mm/min)	F (KN)	d (mm)	Puncture Energy at F-Max (J)
A	25	1.73(0.37)*	75.16(6.12)	449.77(117.22)
	50	2.08(0.21)	84.04(9.52)	645.56(133.38)
	75	1.64(0.15)	84.81(8.67)	508.18(28.69)
	100	1.77(0.18)	81.78(12.13)	559.60(115.54)
	125	1.80(0.29)	83.51(9.37)	585.14(153.68)
B	25	3.87(0.16)	92.69(4.38)	154.71(16.98)
	50	3.94(0.31)	102.02(2.60)	169.85(20.31)
	75	3.72(0.23)	98.38(3.29)	158.63(19.35)
	100	3.80(0.57)	98.95(7.66)	159.27(34.28)
	125	3.98(0.24)	103.72(8.45)	178.32(29.22)
C	25	5.34(0.33)	99.21(4.89)	223.70(34.68)
	50	5.26(0.51)	92.65(6.58)	211.48(30.35)
	75	5.41(0.20)	100.90(3.61)	230.10(15.49)
	100	5.46(0.20)	98.70(3.73)	230.36(21.94)
	125	5.24(0.43)	98.58(3.69)	219.25(20.99)
D	25	5.27(0.18)	109.34(6.23)	244.09(18.02)
	50	4.95(0.38)	104.92(4.50)	212.31(27.97)
	75	5.03(0.50)	103.28(3.07)	210.40(25.19)
	100	6.25(0.24)	111.52(4.96)	290.36(24.95)
	125	6.16(0.26)	110.99(2.05)	291.03(14.37)

*(The value in parenthesis is the related Standard Deviation).

The puncture test was also carried out according to ASTM D4833 [5]. The procedure of this test was the same as the CBR test, but there were some differences. Here the clamp consisted of two circular plates with inner diameters of 45±0.25 mm (*Figure 2a*). The indenter was smaller and its shape was different (*Figure 2b*). The indenter diameter was 8±1 mm, having a flat end with a 45° (0.8 mm) chamfered edge that contacted the specimen surface.

FIGURE 2. (a)Puncture test clamp. (b)Puncture test plunger.

The geotextile specimen was held and secured between these plates by six screws. Then the indenter and the clamp were installed on the Zwick Universal Testing Machine, and ran at a constant rate of elongation, as was mentioned before.

Five specimens were tested for each layer, 25 total specimens, at a standard speed of 300 mm/min.

Based on the load-elongation curves of the Puncture test, similar to the CBR test, the different puncture parameters were measured. The results are shown in *Table III*.

TABLE III. Puncture test results.

Sample	F (KN)	d (mm)	Puncture Energy at F-Max (J)
A	0.36 (0.06)*	24.84 (1.98)*	2.82 (0.54)*
B	0.73 (0.07)*	39.94 (1.53)*	9.37 (0.88)*
C	1.11 (0.08)*	37.27 (1.73)*	13.40 (1.15)*
D	1.14 (0.10)*	40.43 (1.59)*	14.90 (1.63)*

*(The value in parenthesis is the related Standard Deviation).

RESULTS AND DISCUSSION

Geotextile Puncture Mechanism

In each CBR curve, three significant regions were visible. A typical CBR curve is shown in *Figure 3*.

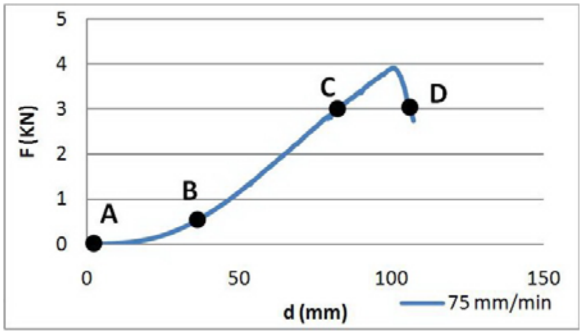


FIGURE 3. A typical CBR curve.

Point A was the beginning of the test where the force and the displacement of the layer were almost zero. In the A-B region, in which the curve has a slight slope, the plunger was just in contact with the specimen surface. At the start of the test, the plunger began to come down, while the spaces between the fibers were empty, and the compression and tensional forces resulted in the movement of the fibers, so the fibers displayed a low resistance to those forces. But, a new arrangement of the fibers resulted in a gentle slope in the A-B region of the curve. *Figure 4* shows the deformation of the layer during the CBR test in the A-B region.

FIGURE 4. Deformation of geotextile layer during CBR test in A-B region.

In the B-C region in which the curve slope was steeper, the fibers were tightly packed together, so they would be in complete contact with each other while the frictional forces increased. Thus, the fibers were locked and not easily moved. This situation is called a Self-Locking mechanism [6]. By continuing the downward movement of the plunger, the tension of the system rose, which resulted in the frictional forces moving the fibers. Understandably, the specimen showed the fibers in their new arrangement which resulted in a higher slope in the B-C region (*Figure 5*)

FIGURE 5. Deformation of geotextile layer during CBR test in A-B region.

In the C-D region, in which the peak of the curve can be seen, the puncture of the layer has occurred. In this region, the fibers were stuck and could not move, so the frictional forces separated the fibers suddenly and punching occurred [6] (*Figure 6*).

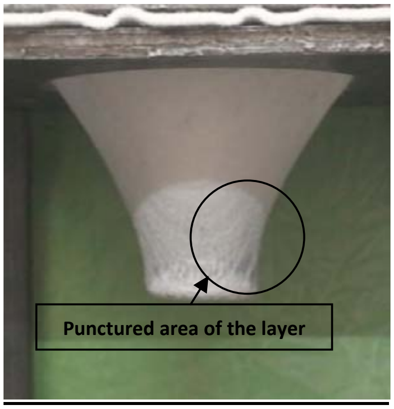


FIGURE 6. Deformation of geotextile layer during CBR test in A-B region.

It should be noted that the puncture mechanism in the Puncture test was the same as the CBR test, just on a smaller scale. As mentioned previously, the CBR plunger diameter was 50 mm while the Puncture indenter diameter was 0.8 mm. The CBR test method was preferred because of the larger plunger size which could not be influenced by the irregularities of fiber densities in the sample [1].

CBR Test Results

On *Table IV*, the parameters, which could affect the CBR and Puncture test variable values, are shown by using ANOVA and multiple-range test methods.

TABLE IV. Effective parameters on CBR tests variables.

	Weight Effect	Test Speed Effect
CBR Force	+	+
CBR Energy	+	+
CBR Strain	+	-

The results of the CBR tests indicated that fabric weight and speed parameters significantly influenced puncture resistance.

It was found that at different test speeds, increasing the fabric weight resulted in increased puncture resistance of the fabrics from 1.8 KN to 5.53 KN (*Figure 7*).

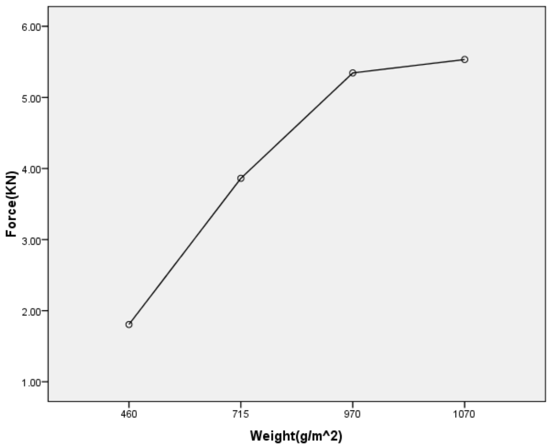


FIGURE 7. CBR puncture resistance of geotextiles with different unit weight.

In fact, due to the increase in the layers' weight, the fibers' entanglement and the higher surface frictional forces, more force was required to make a 3-dimensional deformation and, as a result, punching through the layer. This result also can be attributed to the number of fibers in the layers' cross-section as indicated by the R values in *Table I*. It was shown that, with increased fabric weight, the corresponding R values for layers A, B and C increased. However, due to the close number of fibers in layers D and C, the related puncture resistance value was insignificant.

Of course, the puncture resistance of fabrics that were tested at higher speeds, 100 and 125 mm/min, were significantly higher than the other speed levels (*Figure 8*).

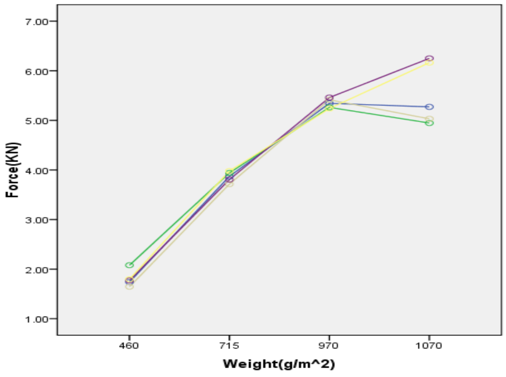


FIGURE 8. CBR puncture resistance of geotextiles with different test speeds.

In fact at higher test speeds, the test would be dynamic instead of static. Thus, in dynamic mode, the structure, especially a compact one, showed more puncture resistance. Also in the higher test speeds, the more speed was required for punching or rupturing the fibers [7]. In this regard, the effect of the different speed levels on the puncture resistance on the heaviest fabric was much more obvious. However, puncture resistance of fabrics at 25, 50 and 75 mm/min were statistically insignificant.

The Duncan test results confirmed this fact. Totally changing the test speed from 25 to 125 mm/min, caused a change of puncture resistance from 3.9 KN to 4.3 KN.

On the other hand, weight and speed significantly influenced the puncture energy as well as the puncture resistance. Nonwoven fabrics at weight values of 460 and 715 g/m^2 exhibited the highest and lowest puncture energy values respectively (*Figure 9*).

The range of the puncture energy as a result of the weight change was 164 J to 550 J in average.

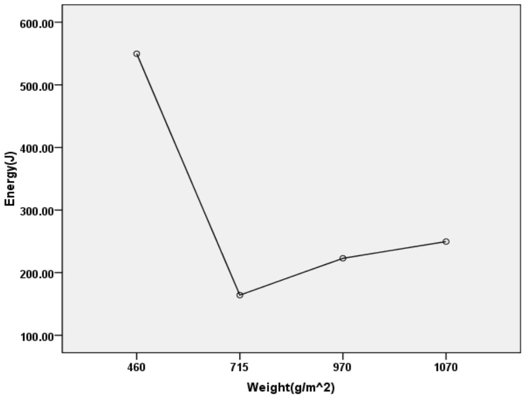


FIGURE 9. CBR puncture energy of geotextile with different unit weight.

Statistical analysis results also showed that the puncture strain energy of the fabric tested at the lowest speed of 25 mm/min was significantly lower than the other speed levels, 50, 100 and 125 mm/min (*Figure 10*).

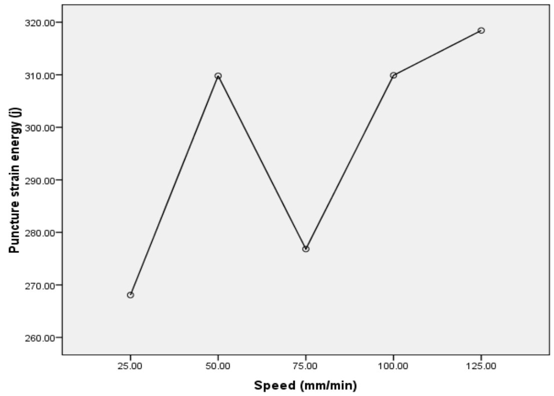


FIGURE 10. CBR puncture energy of geotextiles with different test speeds.

It should be mentioned that the effect of speed on the puncture energy was low and almost negligible.

The other variable parameter was the elongation value, which was influenced by the fabric weight but not speed. It is shown in *Figure 11*, that the elongation of the fabrics, with a weight of 715 and 970 g/m^2, was similar.

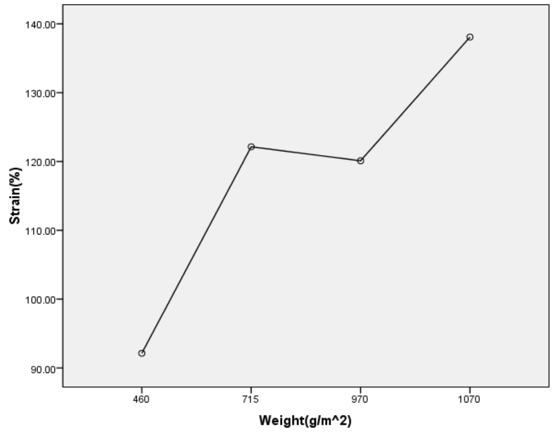


FIGURE 11. CBR elongation of geotextile with different unit weight.

Puncture Test Results

According to *Table V*, the fabric weight was an effective parameter on all the variable parameters of the Puncture test.

TABLE V. Effective parameters on Puncture tests variables.

	Weight Effect
Puncture Force	+
Puncture Energy	+
Puncture Strain	+

Overall, increasing the weight resulted in an increase of the puncture resistance in the range of 359N to 1140N, the puncture energy in the range of 2.8j to 14.9j, and the elongation of the punching point in the range of 67% to 140% (*Figure 12*, *13* and *14* respectively).

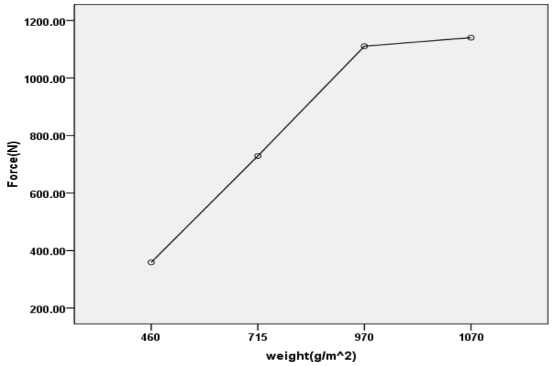


FIGURE 12. Puncture resistance of geotextiles with different unit weights in Puncture test.

In *Figure 12*, the puncture resistance of layers D and C, with a weight of 970 and 1070 g/m^2, was almost identical. The reasoning used to explain the CBR test results could also be used for the Puncture test results. This result could be due to the number of fibers in the layer cross-section (R value), where there was no significant difference between layers C and D (*Table I*).

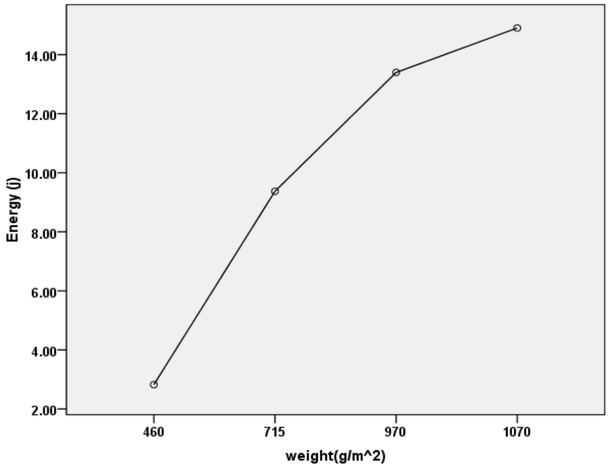


FIGURE 13. Puncture energy of geotextiles with different unit weight in Puncture test.

By comparing the fabrics' puncture resistance in the CBR and Puncture tests, the puncture resistance values in the CBR test were higher than the values in the Puncture test. Because of the small size of the indenter and its special geometrical shape in the

Puncture test, a smaller region of the fabric and fewer fibers were punched. So less force was required to punch the geotextile.

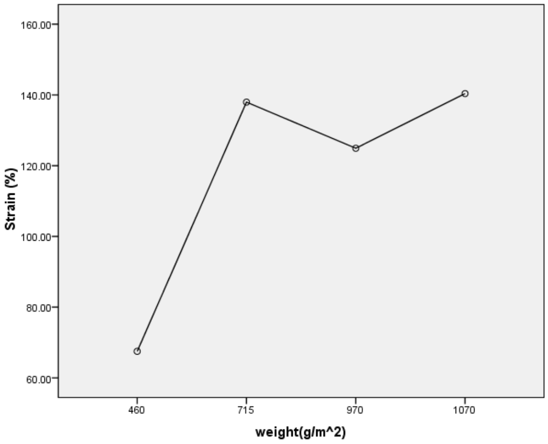


FIGURE 14. Puncture elongation of geotextiles with different unit weight in Puncture test.

CONCLUSION

In this research, the effect of speed and the geotextile's unit weight on the puncture behavior of geotextile fabrics was studied using the CBR test and Puncture test.

The results of the CBR test indicated that the fabric weight and speed parameters significantly influenced puncture resistance as well as puncture energy. It was found that at different speeds, increasing the fabric weight resulted in an increase of puncture resistance, specifically for fabrics tested at higher speeds of 100 and 125 mm/min. Moreover, the fabrics, with a weight of 460 and 715 g/m^2, have the most and the least puncture energy respectively which was in the range of 164 J and 550 J overall, while the effect of speed on puncture energy in the CBR test was low and negligible.

The elongation at the puncture point was another variable parameter which was measured in the CBR test, which was influenced by fabric weight but not speed. Overall, there was an increase in elongation by increasing fabric weight.

On the other hand, in the Puncture test, the fabric weight influenced all the variable parameters of the test.

ACKNOWLEDGMENT

The authors wish to thank Behsaz Nasj Co. for preparing the nonwoven geotextiles and all the peoples who involved for their help and efforts completing this research.

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