CLAMPING MECHANISM EFFECTS ON THE PUNCTURE RESISTANCE TESTS OF HIGH STRENGTH GEOTEXTILES

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ABSTRACT

The tightness of the clamp was found to have a significant influence on the test results. Tests performed by different technicians were also an important variable in the test results. Therefore, the conventional apparatus was modified using a hydraulic clamping mechanism. The revised hydraulic clamping apparatus proved to be effective in saving time when performing the index puncture (ASTM D4833) and the CBR puncture (ASTM D6241) tests on high strength geotextiles. The advantage of the revised apparatus was more important for high strength geotextiles. Using the revised hydraulic clamping apparatus to perform one set puncture resistance could save at least 20 to 25 minutes compared with using the conventional apparatus as shown in ASTM standards. The variation in puncture resistance for the test performed using the revised apparatus was significantly less than that for the test conducted using the conventional apparatus, especially for unskilled technicians. The CBR puncture resistance was about 8 times the index puncture resistance for tested geotextiles.

Key words: Puncture resistance test, geotextile, clamping mechanism.

1. BACKGROUND

A geotextile is a permeable geosynthetic comprised solely of textiles. They are textiles in the traditional sense, but consist of synthetic rather than natural fibers such as cotton, wool, or silk. These synthetic fibers are made into flexible, porous fabrics using standard weaving machinery or matted together in a random or non-woven manner. Some are also knitted. The vast majority of geotextiles are made from polypropylene (PP) or polyester (PET) fibers or yarns. There are at least 100 specific applications for geotextiles. However, the fabric always performs at least one of five discrete functions: separation, reinforcement, filtration, drainage, and containment. At present, the professional groups that commonly use Geosynthetics are geotechnical engineering, transportation engineering, environmental engineering and hydraulics engineering. All of these applications require design procedures that are based on the tensile strength, tear strength and puncture resistance of geotextiles. Generally, grab tensile (ASTM D4632), strip tensile (ASTM D5035), trapezoid tear (ASTM D4533), index puncture (ASTM D4833), and CBR puncture (ASTM D6241) test methods are used to evaluate the engineering properties of geotextiles in the laboratory.

Clamping slippage is a common problem associated with testing high strength geotextiles and related products. To prevent the slippage problem, four to six screws in a conventional test fixture are used to produce the large torque required for each test operation. This operation requires patience and is a time consuming process. Inability to obtain higher puncture resistance is a common phenomenon in puncture resistance tests due to specimen slippage with high strength geotextiles. The clamp tightness was also found to have a significant influence on the test results. Clamping tightness could also vary with the operator or other factors in each test operation. Tests performed by different technicians are also an important variable in the test results. A better clamping mechanism is required to ensure accurate puncture resistance tests for high strength geotextiles or related products. Therefore, we modified the conventional apparatus using a hydraulic clamping mechanism. The clamping mechanism effect on the puncture resistance of high strength geotextiles and related products was investigated in this study.

2. TEST MATERIALS

A black polypropylene (PP) geotextile and a white geotextile woven with a mixture of polyester (PET) and polypropylene (PP) fibers, provided by two local manufactures, were used in this study. The manufactured nominal strength designs for the tested PP geotextile in the machine direction (MD) and cross machine direction (XD) were 80 kN/m and 70 kN/m, respectively. The black PP geotextile was woven from silt-film fibers, 2% carbon black and 1% antioxidants mixed in the PP base resin to produce the PP fibers. The white PET-PP geotextile was produced from two types of multi-filament fibers. The manufactured nominal strength designs for the tested PET-PP geotextile in the MD (polypropylene) and XD (polyester) were 70 kN/m and 120 kN/m, respectively. The typical material properties of the test geotextiles are shown in Table 1.

3. TEST PROGRAM AND EQUIPMENTS

The ASTM D4833, index puncture resistance, and D6241, CBR static puncture strength test methods were investigated in this study. According to the ASTM D4833 and D6241 standard test methods, the geotextile specimen is clamped without tension between circular plates using 6 or 4 screws, respectively.

The puncture resistance test program was conducted with a conventional test apparatus and a revised hydraulic clamping

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Table 1 Engineering properties of the test geotextiles

Engineering properties		Mass per unit area (g/m^2)	Apparent opening size (mm)	Wide width tensile strength (kN/m)	Elongation (%)
Test method		ASTM D5261	ASTM D4751	ASTM D4595	ASTM D4632
PP geotextile	MD	392.72	0.344	85.4	15.53
	XD			58.9	9.48
PET-PP geotextile	MD	488.18	0.323	70.5	17.57
	XD			119.85	24.22

apparatus. Three different technicians performed the test program. One technician, very familiar with both test methods, performed 3 and 5 sets of the puncture resistance tests using the conventional and revised hydraulic apparatus, respectively. The other two technicians performed one set of puncture resistance tests. The purpose of the test program was to evaluate the effect the clamping mechanism and technician on the puncture resistance test results and the time saved for the revised claming mechanism. The time consumed in specimen preparation (drilling holes at screw location), mounting, testing, and demounting each test specimen was recorded for each test specimen.

The puncture tests were performed using a servo control universal test machine with a constant-rate-of compression. The accuracy of the rate of compression was ±0.005 mm/min. The machine was operated using a Window-98 interface with autographic recording and plotting functions. 10,000 N and 200,000 N load cells with an accuracy of ±20 N and 500 N were used to measure the index puncture and CBR puncture resistance, respectively.

4. ASTM D4833 INDEX PUNCTURE TEST

The ASTM D4833 test method suggested a ring clamp apparatus, consisting of concentric plates with an open internal and external diameter of 45 ± 0.025 mm and 100 ± 0.025 mm, respectively. The geotextile specimen was clamped without tension between circular plates using 6 screws. The diameter of the six screw holes used for securing the ring clamp assembly was suggested 8 mm and equally spaced at a radius of 37 mm. The surfaces of these plates could consist of grooves with an O-ring or coarse sandpaper bonded onto the opposing surface. The diameter of the test probe was 8 ± 0.1 mm with a flat end with a 45° and 0.8 mm chamfered edge contacting the test specimen surface.

In addition, a revised hydraulic ring clamp apparatus was introduced in this study, as shown in Fig. 1. This apparatus consisted of a top fixture plate, a bottom fixture plate, a base plate and a hydraulic cylinder. The top fixture plate and the base plate were fixed on each side of two steel rods. The hydraulic cylinder was mounted at the center of the base plate. The bottom fixture plate could be pushed up and down using the hydraulic cylinder against the top fixture plate providing the clamping mechanism. The hydraulic cylinder could provide 69.042 kN of compression force. Both fixture plates consisted of an open internal with diameters of 45 ± 0.025 mm according to the ASTM D4833 test method. The compression pressure at the fixture surface was about 4,900 kPa.

(a) ASTM D4833

(b) ASTM D6241

Fig. 1 Photograph of the revised hydraulic puncture apparatus for ASTM D4833 index puncture and ASTM D6241 CBR puncture resistance tests

During the puncture test, the ring clamp apparatus was fixed at the center of the machine base frame. The test probe was attached with the load indicator at the top frame of the test machine pushing downward at a speed of 300 ± 10 mm/min until rupture occurred. The maximum force is puncture strength value. Because no reliable tested geotextiles data were provided, each set of tests consisted of 15 specimens. The size of the specimen was 100 by 100 mm. The test specimens were conditioned and tested in a temperature and humidity controlled room. The controlled temperature was 21 ± 2°C and the relative humidity was 65 ± 5 %.

5. ASTM D6241 CBR PUNCTURE TEST

The CBR puncture test mechanism is quite similar to the index puncture test mechanism. Larger size fixture plates and plunger are used to provide a multidirectional force on the geotextile. The internal diameter of the fixture plates is 150 mm and the suggested external diameter is 250 mm. The uniform plunger diameter is 50 ± 1 mm with a 2.5 ± 0.5 mm radial edge.

A guide block may be used to help seat the test specimen being clamped. The geotextile specimen is clamped without tension between circular plates using 4 screws. The screw hole diameter used for securing the ring clamp assemblage is suggested as 11 mm, equally spaced at a diameter of 220 mm. The fixture plate surfaces can consist of grooves with rubber O-rings or coarse sandpaper bonded onto the opposing surfaces. The ring clamp apparatus is fixed at the center of the machine base frame. The test plunger is attached with a load indicator at the top frame of the test machine pushing downward at a speed of 50 mm/min until rupture occurs. The initial peak force is read as the puncture strength and the associated displacement is recorded during the test. Because no reliable geotextile test data are available, each set of tests consisted of 10 specimens. The test specimen diameter was 250 mm. Test specimens were conditioned and tested in a temperature and humidity controlled room. The controlled temperature was 21 ± 2°C and the relative humidity was 50 to 70%.

A revised hydraulic clamp apparatus is introduced as shown in Fig. 1. This apparatus has a structure similar to the CBR test mechanism. The internal and external dimensions of the fixture plates were designed according to the ASTM specifications. The top fixture and base plates were fixed at each end of three equally spaced steel rods. The bottom fixture plate could be pushed using a hydraulic cylinder, that could provide 107.861 kN clamping force. The compression pressure at the fixture surface was about 4,900 to 11,772 kPa. A circular guide plate with a 110 mm hole at the center could be moved up to the desired location to help seat the specimen being clamped. The guide plate could then be moved down after the specimen was clamped.

6. RESULTS AND DISCUSSION

As discussed earlier, the geotextile specimen was clamped without tension between circular plates using 4 to 6 screws for both puncture tests. After cutting the test sample to the desired specimen size, the necessary clamping holes of the test specimen punched at the screw locations using an electrical hot puncher. However, it was unnecessary to punch screw holes for the tested specimen using the revised apparatus. The typical required time to perform each ASTM D4833 or D6241 puncture test procedure for the PP geotextile using the conventional apparatus are summarized in Tables 2 and 3, respectively. The time for the punching screw holes, clamping, and de-clamping specimen by the skilled and un-skilled technicians are included. As shown in the tables, 15 to 25 more minutes were required to punch the screw holes for each set of specimen in both puncture tests using the conventional apparatus than with the hydraulic apparatus. The unskilled technician required six to twelve more minutes to perform each ASTM D4833 or D6241 puncture test using the conventional apparatus. For the tests performed using the hydraulic apparatus, no significant difference in time was consumed for performing ASTM D4833 puncture tests. However, the unskilled technician required 20 more seconds to clamp and de-clamp test specimen for ASTM D6241 test method. The typical required time to clamp and de-clamp specimen for ASTM D4833 and D6241 puncture test method for skilled technician is about 10 seconds and 20 seconds, respectively.

The average total time for performing a specimen test by skilled and unskilled technicians for both test methods is summarized in Table 4. Approximately, 25 to 80 more seconds were required to perform each specimen test for both test methods by unskilled than skilled technicians. The difference in required time to perform puncture tests for each specimen by unskilled technicians was more significant than that performed by skilled technicians. Based on the information shown above, the revised apparatus saved at least 20 to 25 minutes in performing the index or CBR puncture test over the conventional apparatus.

Table 2 Summary of typical consuming time for each step performing ASTM D4833 index puncture test for PP geotextile using the conventional and hydraulic apparatus

Specimen No.	Conventional apparatus						Hydraulic apparatus			
	Skilled technician			Unskilled technician			Skilled technician		Unskilled technician	
	Hole punching (sec)	Clamping (sec)	De-clamping (sec)	Hole punching (sec)	Clamping (sec)	De-clamping (sec)	Clamping (sec)	De-clamping (sec)	Clamping (sec)	De-clamping (sec)
1	45	54	18	67	62	17	5	3	7	3
2	48	54	17	72	55	13	5	3	5	3
3	46	57	18	59	48	11	5	3	5	3
4	50	61	18	68	59	13	5	3	5	3
5	45	55	19	62	52	13	5	3	5	3
6	47	59	16	57	51	11	5	3	5	3
7	46	55	18	56	44	10	5	3	4	3
8	44	57	16	65	48	12	5	3	5	3
9	45	59	15	63	42	10	5	3	6	3
10	44	56	18	65	49	10	5	3	5	3
11	53	55	18	59	52	14	5	3	4	3
12	44	57	16	56	47	13	5	3	6	3
13	43	53	18	56	49	12	5	3	4	3
14	42	62	16	57	50	12	5	3	5	3
15	45	58	17	57	45	13	5	3	6	3
Average	45.8	56.8	17.2	61.3	50.2	12.3	5.0	3.0	5.1	3.0
Standard deviation	0.73	0.68	0.30	1.33	2.15	0.64	0.00	0.00	0.22	0.00

Table 3 Summary of typical consuming time for each step performing ASTM D6241 CBR puncture test for PP geotextile using the conventional and hydraulic apparatus

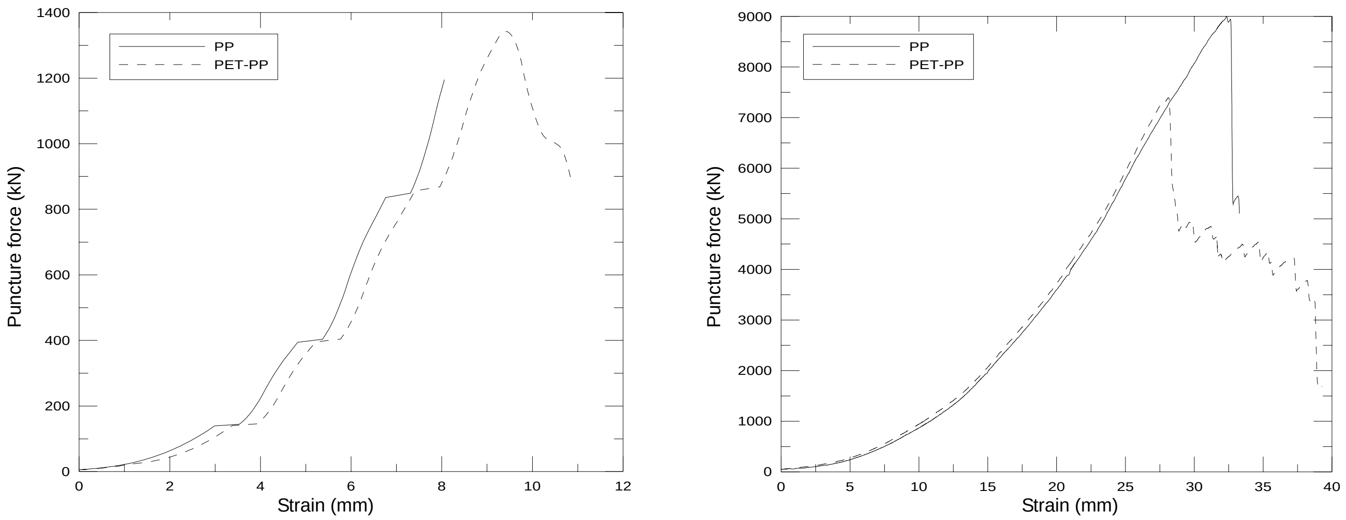
Specimen No.	Conventional apparatus						Hydraulic apparatus			
	Skilled			Unskilled			Skilled		Unskilled	
	Hole punching (sec)	Clamping (sec)	De-clamping (sec)	Hole punching (sec)	Clamping (sec)	De-clamping (sec)	Clamping (sec)	De-clamping (sec)	Clamping (sec)	De-clamping (sec)
1	33	56	12	67	161	14	16	3	41	7
2	41	55	12	54	89	13	17	3	42	7
3	40	62	12	55	143	15	18	3	32	7
4	36	54	12	58	78	13	17	3	30	7
5	38	52	12	65	69	13	15	3	33	7
6	38	52	12	57	85	14	15	3	35	7
7	33	57	12	59	112	14	15	3	39	7
8	41	56	12	58	78	15	17	3	33	7
9	39	52	12	63	142	15	19	3	36	7
10	37	58	12	64	123	16	17	3	35	7
Average	37.6	55.4	12	60	108	14.2	16.6	3	35.6	7
Standard deviation	1.01	1.05	0.00	1.41	10.44	0.34	0.39	0.00	1.28	0.00

Table 4 Summary of the average total consuming time performing ASTM D4833 and D6241 puncture tests using the conventional and revised apparatus

Technician	Test set No.	ASTM D4833				ASTM D6241			
		Conventional apparatus (sec)		Hydraulic apparatus (sec)		Conventional apparatus (sec)		Hydraulic apparatus (sec)	
		PP	PET-PP	PP	PET-PP	PP	PET-PP	PP	PET-PP
Skilled	1	128.8	116.2	8.0	8.0	143.2	111.0	28.4	21.0
	2	119.8	116.4	8.0	8.0	115.8	109.2	24.4	22.2
	3	112.8	106.2	8.0	8.0	105.0	112.2	22.2	23.4
	4	…	…	8.0	8.0	…	…	20.8	22.6
	5	…	…	8.0	8.0	…	…	19.6	22.2
No.1 unskilled	1	148.5	132.1	10.8	9.9	182.2	154.8	42.6	38.0
No.2 unskilled	1	133.5	143.3	8.1	7.4	196.8	173.1	35.1	31.1

Typical puncture force versus displacement curves for the ASTM D4833 and D6241 test methods are shown in Fig. 2. The curves for the CBR puncture test method were smoother than those for the index puncture test. The peak puncture rod displacement associated with the ASTM D6241 test method was about three times more than that for the ASTM D4833 test method.

The typical puncture resistance for one set of puncture test results performed by the skilled or unskilled technicians using the conventional or revised apparatus for the PP geotextile are summarized in Tables 5 and 6 for the ASTM D4833 and D6241 test methods, respectively. As shown in the tables, the average puncture resistance for the test performed by skilled or unskilled technicians using the conventional or hydraulic apparatus was quite similar. However, the standard deviation for tests performed by the unskilled technician was significantly grater than that performed by the skilled technician.



(a) ASTM D4833 (b) ASTM D6241

Fig. 2 Typical test results using the revised hydraulic clamping apparatus for ASTM D4833 index puncture and ASTM D6241 CBR puncture resistance tests

Table 5 Summary of typical index puncture (ASTM D4833) resistance of PP geotextile for the test performing by skilled and unskilled technician using the conventional and revised apparatus

Specimen No.	Conventional apparatus		Hydraulic apparatus	
	Skilled	Unskilled	Skilled	Unskilled
	Strength (N)	Strength (N)	Strength (N)	Strength (N)
1	1197.21	1314.12	1195.45	1047.62
2	1186.42	1117.01	1233.61	1398.30
3	887.22	945.23	1089.99	1288.56
4	1114.62	1384.79	1022.79	1160.47
5	1053.20	848.61	920.47	1287.49
6	1040.74	1367.73	1143.45	1069.44
7	999.05	1353.62	1067.13	984.98
8	1352.80	909.44	1162.19	1220.33
9	1148.55	904.67	1222.03	1047.45
10	1272.46	1407.56	1054.97	1063.14
11	1019.16	919.69	1035.25	1294.47
12	980.71	1018.85	1063.80	1218.02
13	992.77	1340.44	1029.66	1275.06
14	943.72	1152.82	1070.76	978.95
15	1196.96	1125.22	928.22	968.83
Average	1092.37	1140.65	1082.65	1153.54
Standard deviation	130.80	206.155	94.61	138.90

In addition, the average puncture strength and its associated standard deviation for the test performed by skilled and unskilled technicians using ASTM D4833 and D6241 test methods are summarized in Tables 7 and 8. As shown in the tables, the test results performed by the skilled technician were significantly more uniform compared with those performed by the unskilled technician. Similarly, the standard deviation associated with the test performed using the hydraulic apparatus was relatively lower than that associated with the test conducted using the conventional apparatus. This reflected that the puncture resistance determined using the conventional apparatus varied more significantly than that performed using the revised apparatus.

By comparing the data shown in Tables 7 and 8, the test results for ASTM D4833 varied much less than those for the ASTM D6241 test method. The average puncture resistances and standard deviations associated with the PET geotextile varied more than those associated with the PP geotextile. In addition, the CBR puncture resistances for both tested geotextiles were approximately 8 times the index puncture resistances for the corresponding geotextiles. This value was slightly higher than the ratio published by Koerner (2002).

Table 6 Summary of typical CBR puncture (ASTM D6241) resistance of PP geotextile for the test performing by skilled and unskilled technician using the conventional and revised apparatus

Specimen No.	Conventional apparatus		Hydraulic apparatus	
	Skilled	Unskilled	Skilled	Unskilled
	Strength (N)	Strength (N)	Strength (N)	Strength (N)
1	9052.77	8928.67	8793.98	9295
2	9673.25	8403.82	8581.20	8702
3	8931.12	9764.09	8703.43	8790
4	8795.06	9643.52	8792.51	9073
5	9728.97	10034.94	8459.65	9222
6	8916.11	9101.13	8352.53	8659
7	9913.79	9567.40	8673.81	8996
8	9547.78	10371.72	8494.58	8909
9	9353.05	9549.54	8719.91	8817
10	9746.92	9296.05	9119.28	9154
Average	9365.88	9466.09	8669.09	8961.70
Standard deviation	554.93	563.78	155.86	221.38

Table 7 Summary of average index puncture (ASTM D4833) resistance for the test performing by skilled and unskilled technician using the conventional and revised apparatus (unit: N)

Technician	Test set No.	Conventional apparatus				Hydraulic apparatus			
		PP		PET-PP		PP		PET-PP	
		Strength (N)	Standard deviation	Strength (N)	Standard deviation	Strength (N)	Standard deviation	Strength (N)	Standard deviation
Skilled	1	1087.63	15.54	1092.26	11.80	1082.65	9.64	1293.06	11.15
	2	1092.37	13.33	1068.15	9.32	1120.77	10.45	1333.77	10.06
	3	1159.76	14.28	938.34	13.62	1141.64	10.98	1254.68	10.24
	4	…	…	…	…	1158.25	9.23	1250.78	8.77
	5	…	…	…	…	1167.30	14.39	1218.45	14.74
No.1 unskilled	1	1140.65	21.01	943.87	12.32	1204.11	13.37	1271.59	19.32
No.2 unskilled	1	1091.08	15.05	861.94	12.42	1153.54	14.16	1220.43	9.40

Table 8 Summary of average CBR puncture (ASTM D6241) resistance for the test performing by skilled and unskilled technician using the conventional and revised apparatus

Technician	Test set No.	Conventional apparatus				Hydraulic apparatus			
		PP		PET-PP		PP		PET-PP	
		Strength (N)	Standard deviation	Strength (N)	Standard deviation	Strength (N)	Standard deviation	Strength (N)	Standard deviation
Skilled	1.00	9263.35	33.43	9157.60	53.54	8685.31	29.60	7491.86	53.07
	2.00	9365.88	41.89	8860.66	45.40	8886.60	31.30	8396.62	26.10
	3.00	9629.91	56.57	8290.38	49.22	8768.50	38.41	8434.76	29.29
	4.00	…	…	…	…	8619.07	15.89	7886.37	24.56
	5.00	…	…	…	…	8913.98	33.63	7132.75	86.03
No.1 unskilled	1.00	9466.09	57.47	9097.81	40.02	8961.70	22.57	8364.67	35.00
No.2 unskilled	1.00	8832.56	103.09	7980.76	127.85	9158.41	52.402	8084.32	99.35

Based upon the discussion shown above, the revised apparatus was proven effective and time saving in performing the index puncture and CBR puncture tests on high strength geotextiles. Moreover, using the revised hydraulic apparatus to perform the puncture test would significantly increase the reliability of the test results. This advantage is more important for puncture tests performed by unskilled technicians when testing of high strength geotextiles.

7. SUMMARY AND CONCLUSIONS

The objective of this study was to investigate the clamping mechanism effects on the puncture resistance of high strength geotextiles and related products. The clamping mechanism effects on the puncture test methods, ASTM D4833, index puncture resistance, and the ASTM D6241, CBR static puncture strength, were investigated. Conventional and revised hydraulic clamping apparatuses were used in this comparison study. The test samples included a medium high strength Polypropylene slit-film geotextile and a high strength geotextile woven from polyester and polypropylene multiple-filaments. One skilled and two unskilled technicians performed the comparison test program. The skilled technician performed three to five set tests and the unskilled technicians conducted only one set of tests. The following conclusions are based on the test results.

1. The revised hydraulic clamping apparatus was proven effective and time saving in performing the index puncture (ASTM D4833) and the CBR puncture (ASTM D6241) tests on high strength geotextiles. The advantage of the revised apparatus is more important for high strength geotextiles.
2. Using the revised hydraulic clamping apparatus to perform one set of puncture resistance tests saves 20 to 25 minutes compared with performing the test using the conventional apparatus.
3. The puncture resistance variation for the test performed using the revised apparatus was significantly less than that for the test conducted using the conventional apparatus, especially for unskilled technicians.
4. The peak puncture rod displacement associated with the ASTM D6241 test method was about three times more than that for the ASTM D4833 test method for the test materials. The CBR puncture resistance (D6241) was about 8 times the index puncture resistance (D4833) for tested geotextiles.
5. The average puncture resistances and standard deviations associated with the test PET geotextile varied more than those associated with the test PP geotextile.

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