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A Comparison of Tensile and Puncture Properties of Nonwoven Fabrics

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1. Introduction

Although many papers have been published for the mechanical properties of nonwoven fabrics, there is no report on the relationship of tensile and puncture properties. For the further applications of lightweight nonwoven products like protective clothing materials, thorough understanding of the relationship should be preceded when they are subjective to puncture force.[1, 2]

This paper focuses on the tensile test methods which could predict the puncture properties of nonwoven fabrics. In the present work, two test methods are used for the tensile property : uniaxial and biaxial tests. The puncture properties are mainly dependent on the diameter and shape of penetrator. The tensile strength can be used to calculate puncture force by modified Cazzuffi's equation. If any condition of tensile test is similar to puncture test, the test method will be the best agreement for predicting the puncture properties.

2. Cazzuffi and Venesia's Equation

Cazzuffi and Venesia represent equation (1) as a relationship between tensile and puncture strength for isotropic nonwoven fabrics.[3]

$$F_p = 2\pi r \sigma_t \qquad (1)$$

where, F_p = puncture force (kgf), r = radius of penetrator (m), and σ_t = tensile strength (kgf/m). If any tensile test condition is similar to puncture test, the tensile strength is given by equation (2).

$$\sigma_t = \frac{\sigma_t' + \sigma_t''}{2} \qquad (2)$$

where, σ_t', σ_t'' = tensile strength in MD and CD, respectively. By using these relations, the theoretical puncture force can be calculated by equation (3).

$$F_p = \pi r\left(\sigma_t' + \sigma_t''\right) \qquad (3)$$

3. Experimental Procedure

We adopt Grab(ASTM D5034-95), Cut Strip(ASTM D5035-95) and Wide Width Strip test(ASTM D4595-86) for uniaxial tensile property and adopt Puncture Resistance test (ASTM D4833-88) by Instron m/c working in a compression mode. For the biaxial test, specimen is mounted to the clamp segments and then cut slits perpendicular to the boundaries of the specimen. The extension speed is only 8cm/min. with biaxial test and extension ratio is equal in a both directions.

The ASTM Test Method requires a determined constant rate of extension, but in this study, three extension speeds are used for the comparison of effect with extension speeds.

4. Results and Discussion

Table 1 shows the experimental tensile properties and we can also calculate theoretical puncture force from the data. As mechanical strength of the fabrics is dependent on the bonding methods, TNF(Thermal bonded Nonwoven fabric) shows the lowest values and CNF(Chemical bonded Nonwoven fabric) is relatively low values. From the results, low CV values indicate a good reproducibility of the mechanical properties.

Since the most of nonwovens show orthotropic behavior, the Cazzuffi's equation can be modified to predict puncture force by equation (3). When average tensile strength of machine and cross direction value is also calculated, it can be found that the value shows considerable difference with each test method.

And specifically there is the best correlation between theoretical puncture force calculated by biaxial tensile strength and experimental force. Also Wide Width Strip test shows a good correlation than Grab and Cut Strip tests for puncture force. The puncture strain is approached to biaxial tensile strain. However, it has a little difference with SNF(Spunbonded Nonwoven Fabric). When puncture force is applied to the specimen, reactive force is happened with all the direction. Consequently biaxial test condition is the most similar condition with puncture test. In order to predict puncture property, it is the most important factor to select similar experimental condition with puncture test.

5. Conclusions

The purpose of this research is to compare the theoretical puncture force calculated by tensile property and experimental puncture force with tensile test methods. The conclusions obtained from the study are as follows: (1) The mechanical properties are increased with test speed, especially for CNF, (2) Cazzuffi's equation can be modified to predict puncture force of orthotropic nonwoven fabrics, (3) A good correlation between calculated and experimental puncture force is evaluated with the order of Biaxial, Wide Width Strip, Cut Strip, and Grab method.

References

1. J. Lara, N.F. Nelisse, S. Cote, and H.J. Nelisse, Performance of Protective Clothing, Vol 4, pp26-37 (1992)
2. W.R. Dordogne, Melliand Textiberichte International, Vol 67, pp E353-356 (1986)
3. D. Cazzuffi and S. Venesia, Proceedings of the 3rd International Conference on Geotextiles, Vienna, Austria, (1986)

Table 1. Mechanical Properties of Nonwoven Fabrics (Test Speed:8.0cm/min)

Samples	Grab Test			Wide Width Strip Test			Cut Strip Test			Biaxial Test			Puncture Test	
	Strength (Kgf/m) MD (CV) CD (CV)	P.F (Kgf)	Strain (%) MD (CV) CD (CV)	Strength (Kgf/m) MD (CV) CD (CV)	P.F (Kgf)	Strain (%) MD (CV) CD (CV)	Strength (Kgf/m) MD (CV) CD (CV)	P.F (Kgf)	Strain (%) MD (CV) CD (CV)	Strength (Kgf/m) MD (CV) CD (CV)	P.F (kgf)	Strain (%) MD (CV) CD (CV)	Force (CV) (Kgf)	Strain(CV) (%)
SNF1	700.2 (4.8) 472.0 (8.6)	14.72	45.1 (4.4) 59.0 (8.7)	396.5 (8.1) 291.8 (5.3)	8.65	29.3 (4.3) 37.7 (8.1)	244.6 (8.1) 193.1 (9.1)	5.50	31.1 (8.9) 50.8 (7.6)	595.1 (5.1) 234.2 (6.2)	10.42	20.9 (4.3) 20.7 (2.1)	10.69 (5.3)	22.5 (3.7)
SNF2	277.4 (1.1) 261.5 (2.2)	6.77	68.0 (3.1) 127.7(6.8)	109.3 (4.6) 83.2 (3.1)	2.42	84.8 (9.8) 126.8 (2.7)	102.2 (7.4) 80.9 (3.4)	2.30	82.1 (8.5) 144.4 (5.8)	141.5 (4.9)* 75.1 (5.1)*	2.72	24.0 (3.7)* 24.0 (3.7)*	3.13 (1.7)	26.4 (5.2)
CNF1	209.1 (4.4) 45.6 (3.0)	3.20	16.1 (2.7) 56.9 (5.9)	134.0 (4.3) 15.1 (6.4)	1.87	14.2 (4.5) 22.3 (3.1)	137.4 (1.4) 11.3 (4.2)	1.89	16.1 (1.2) 24.3 (2.9)	145.0 (2.8) 23.4 (5.1)	2.12	5.9 (2.0) 3.9 (6.3)	2.02 (6.2)	11.6 (3.5)
CNF2	144.9 (3.1) 31.8 (3.9)	2.22	11.7 (4.2) 43.7 (7.4)	90.1 (1.5) 11.9 (7.4)	1.28	9.7 (4.5) 19.6 (7.2)	85.3 (2.2) 8.6 (4.1)	1.18	13.7 (1.9) 26.9 (9.6)	98.4 (5.5) 15.7 (4.8)	1.43	5.5 (3.0) 3.6 (4.7)	1.39 (4.5)	7.7 (4.4)
TNF1	78.3 (2.4) 24.7 (5.4)	1.29	7.4 (7.8) 23.3 (5.9)	47.8 (3.7) 10.9 (3.4)	0.74	5.7 (2.3) 15.2 (6.0)	49.3 (3.3) 10.6 (4.8)	0.75	7.6 (4.3) 21.5 (0.8)	48.8 (6.8) 14.9 (3.1)	0.80	3.1 (4.7) 1.8 (3.4)	0.88 (5.8)	5.4 (5.7)
TNF2	62.2 (5.2) 23.8 (4.5)	1.08	10.2 (1.8) 20.2 (4.6)	42.8 (4.8) 9.9 (4.8)	0.66	8.5 (8.7) 11.3 (7.6)	40.1 (3.3) 9.4 (1.7)	0.62	11.9 (2.9) 18.2 (5.3)	39.9 (5.6) 17.8 (4.8)	0.72	3.0 (5.2) 3.0 (4.7)	0.75 (5.2)	5.9 (5.0)

CV : Coefficient of Variation (%)

P.F : Calculated puncture force by equation (3)

* : No breaking