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Rotational Dragging-Based Investigation of Frictional Properties of Nonwoven Fabrics

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Abstract: Friction, a quality-related property, governs not only the efficiency of processing operations but also the quality and performance of the final product. In this work, the frictional characteristics of 100 % polyester, nylon, and polypropylene spunbond nonwoven fabrics bonded with three bonding patterns and the differences in fabric density were tested. A whisker-type tactile sensor machine that can measure the coefficient of friction regardless of the tracing direction was used. Stick-slip trace changes according to the fabric surface morphology were observed. Furthermore, it was found that the bonding method, component filament, and fabric density have a significant influence on the frictional characteristics of spunbond nonwoven fabrics.
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1. Introduction

The spunbond process is widely used in the manufacturing of nonwovens and has seen a significant increase in nonwoven fabric usage in various sectors. Therefore, analysis of mechanical, physical, and hand-related properties of spunbond nonwoven plays an important role in obtaining the desired quality product. Since friction is one of the quality-related properties, there have been a number of investigations into the frictional behavior of spunbond nonwovens at various testing conditions such as different normal pressures, sliding velocities and types of detector or abrasive.

The applied force, fabric density, raw material, and fabric directions (the machine direction, MD and the crosswise direction, CD) impact the frictional properties of spunbond nonwoven fabrics [1]. A friction test was conducted on spunbond nonwovens under different loads and different friction environments (fabric-abrasive wool fabric, wood, and metal). It was concluded that applied force, weight, rubbed surface, fabric directions, and fiber type are some impact factors of the friction behavior of fabrics [2]. Coulomb stated that the static friction force needed to initiate sliding is greater than the kinetic friction force required to maintain sliding. Therefore, the friction trace is intermittent, and/or the stick-slip phenomenon (SSP) occurs in a friction test [3]. It is clear that the stick-slip trace (SST) of thermally bonded nonwoven fabrics changes from one to another because of the uneven surface morphology that results from the loop of fibers, overlapping of fibers at bonding points, and fiber deformation at bonding points owing to melting. Moreover, the testing speed, the thermal bonding temperature and dwell time, and the cross-sectional shape of the component fiber also affects the frictional properties [4].

In the Kawabata system, a surface tester (KES-FB 4) and other frictional testing methods (for example, horizontal and inclined plane experimental devices) can quantify the frictional resistance in both the machine direction and the crosswise direction of the fabric. However, a simple whisker-type tactile sensor friction testing machine can measure the frictional resistance in all directions of woven fabric, and the frictional characteristics can also be used to

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determine the hand value of woven fabrics [5,6].

The goal of this study is to investigate the frictional property of spunbond nonwoven fabrics by rotational dragging. A whisker-type tactile sensor friction testing machine was used to accomplish this goal. The main merit of using a whisker sensor is that it can detect the friction coefficient of the fabric surface in all directions within a short period. Therefore, it is possible to determine the variation in frictional resistance of a spunbond nonwoven fabric surface relative to the dragging direction and specific surface geometry of each bonding method. In other words, the difference in surface geometry can be detected simultaneously during friction measurement. In this study, the SST of the friction coefficient of spunbond nonwovens and the corresponding mean deviation trace were discussed. Further, the effects of fabric properties, bonding patterns, component filaments and fabric weight on the frictional characteristics value were investigated.

2. Experimental Method

2.1 Testing Method

A schematic diagram of the whisker-type tactile sensing machine and its sensor unit, which can measure the normal force and friction force simultaneously, is shown in Figure 1. The whisker sensor consists of a base acrylic plate on which three strain gauges are pasted. Piano wire or sensor wire (0.5 mm in diameter) is attached to this plate through a piece of an acrylic plate (10 × 5 mm^2) [5,6,7].

A nonwoven sample (12 × 12 cm^2) is placed on the horizontal circular sample stage with an iron ring holder and clippers. When the desired weight is placed on the sensor, the sensor wire is brought into contact with the sample surface and thrusts into it. The friction force is generated between the fabric surface and sensor wire under the influence of normal force while the sample stage is kept in motion. These two forces are transmitted to the base acrylic plate and results in strain on the three strain gauges.

Because these strain gauges are in a Wheatstone bridge, the output voltage is directly proportional to the strain caused by the friction and normal force. An encoder fitted under the sample stage detects the position of the sample. With the aid of a data acquisition system and wave logger software, the friction force and normal force are recorded. Hence, the coefficient of friction is calculated by taking the ratio of these two forces [5,6]. Measurement were taken 10 times for each kind of sample, and the coefficient of friction, μ was calculated by averaging these data from the 10 iterations. Then, the mean coefficient of friction and mean deviation that represents the scatter of the coefficient of friction around its mean value were calculated by averaging every 5° of trace angle.

The formulae are expressed in equations (1) and (2). In this experiment, 30 g of weight was used as a normal load, and the dragging speed of the sensor wire was 1 mm/s. The experiment was carried out in a standard testing room (20 ± 2 °C and 65 ± 2 % RH).

Mean coefficient of friction, $\bar{\mu} = \frac{1}{n} \sum_{i=1}^{n} \mu_i \cdots\cdots (1)$

Mean deviation, $\mu_A = \frac{1}{n} \sum_{i=1}^{n} |\mu_i - \bar{\mu}| \cdots\cdots\cdots\cdots (2)$

where n = the number of data in 5° of dragging angle.

2.2 Dragging Angle

In order to determine the friction coefficient value against all directions of the nonwoven fabric, the dragging angle θ is defined. The dragging angle θ is 0° when the sensor wire is perpendicular to the

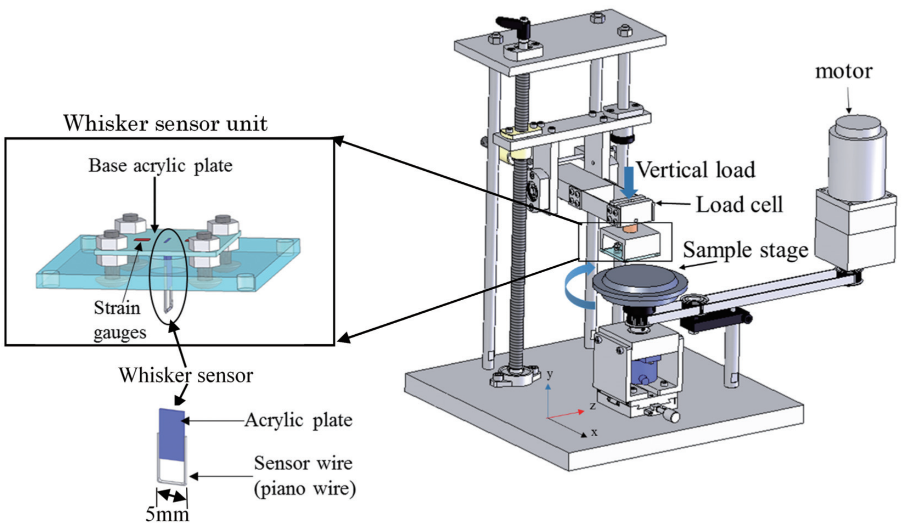


Fig. 1 Whisker-type tactile sensor friction testing machine and its sensor unit

machine direction of the sample. Hence, the dragging angle θ becomes 90° when the sensor wire is parallel to the machine direction of the nonwoven fabric. Figure 2 shows the relative position of the sensor wire in different directions during testing. The direction of the friction force is opposite to the direction of sample rotation.

2.3 Material

A total of 31 commercial spunbond nonwoven fabrics produced by Asahi Kasei Co.,Ltd., were used for experimental study. The spunbond nonwovens are made from a sheet of web in which synthetic long filaments are uniformly distributed. They are bonded by thermocompression [8,9]. Table 1 illustrates some physical characteristics of the samples. The samples are self-bonded nonwovens composed of 100% polyester, nylon, and polypropylene. Three patterns (minus pattern, point pattern, and weave pattern) are used for the bonding web. According to the fiber density per unit area and the bonding method, the

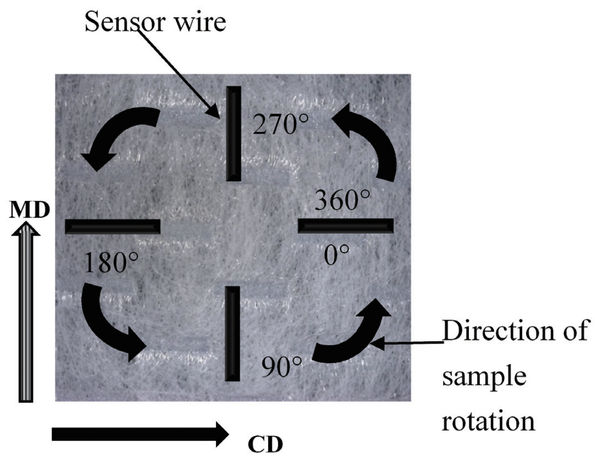


Fig. 2 The relative position of sensor wire during testing

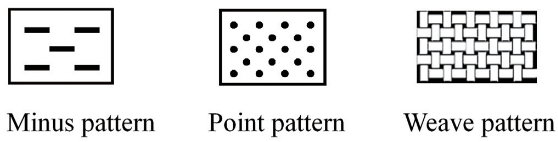


Fig. 3 Bonding patterns

Table 1 Some physical characteristics of samples

	No.	Code No.	Fabric Weight (g/m^2)	Thickness (mm)	Tensile strength N/(5 cm)		Breaking elongation (%)	
					MD	CD	MD	CD
Minus Pattern	1	AE 0	15	0.11	45	15	20	25
	2	AE 1	20	0.14	75	25	25	30
	3	AE 2	30	0.2	140	40	25	30
	4	AE 3	40	0.24	200	60	30	35
	5	AE 4	50	0.28	250	80	30	35
	6	AE 5	70	0.35	330	110	30	35
	7	AN 1	20	0.15	55	20	25	40
	8	AN 2	30	0.21	95	35	30	45
	9	AN 3	40	0.27	150	50	30	45
	10	AN 4	50	0.32	190	65	35	50
	11	AN 5	70	0.4	285	110	35	50
Point Pattern	1	BP 0	15	0.15	40	10	45	65
	2	BP 1	20	0.19	55	14	45	65
	3	BP 2	30	0.25	85	22	50	70
	4	BP 3	40	0.31	120	35	50	70
	5	BP 4	50	0.38	150	45	50	70
	6	BP 5	70	0.46	200	70	50	70
	7	BN 1	20	0.16	45	13	25	30
	8	BN 3	40	0.26	125	40	30	35
	9	BN 4	50	0.31	155	55	30	35
	10	BN 5	70	0.38	255	100	30	35
Weave Pattern	1	CE 1	15	0.13	65	20	25	25
	2	CE 2	20	0.17	110	40	25	30
	3	CE 3	30	0.19	150	55	30	30
	4	CE 4	40	0.21	195	75	30	30
	5	CE 5	50	0.25	270	115	30	30
	6	CN 1	70	0.13	65	20	25	25
	7	CN 2	20	0.17	110	40	25	30
	8	CN 3	40	0.19	150	55	30	30
	9	CN 4	50	0.21	195	75	30	30
	10	CN 5	70	0.25	270	115	30	30

Note: A, B and C mean minus, point and weave pattern respectively.
E, N and P refer Polyester, Nylon and Polypropylene spunbond nonwoven respectively.

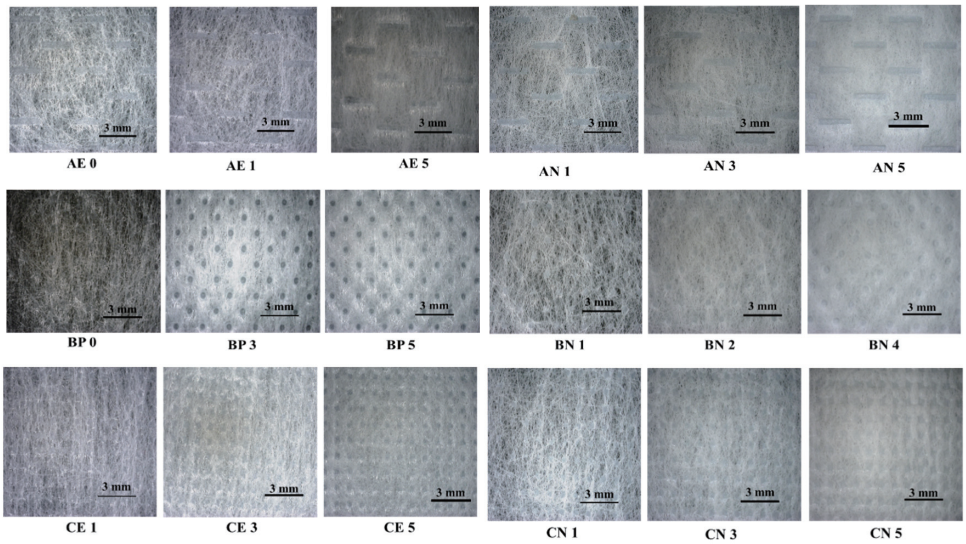


Fig. 4 Surface morphology of some samples

thermally bonded nonwoven fabrics are soft to hard, and some are similar to paper.

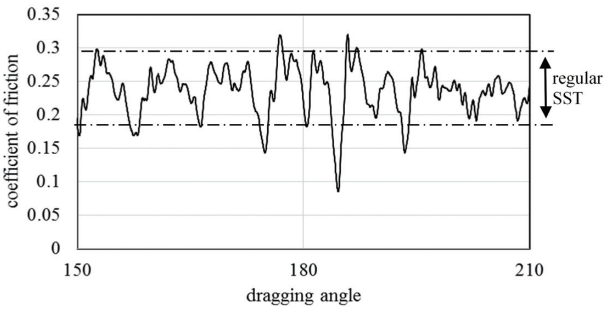
Figure 3 shows a schematic diagram of different bonding patterns, and Figure 4 displays the surface morphology of some samples examined by a high-magnification observation system before testing. It can be seen that the higher the fabric weight, the clearer the bonding pattern. These fabrics are used in industrial materials, building materials, agricultural materials, interior bedding, household miscellaneous goods, automotive materials, various kinds of filters, various coatings, and laminated base fabrics [10].

3. Results and discussion

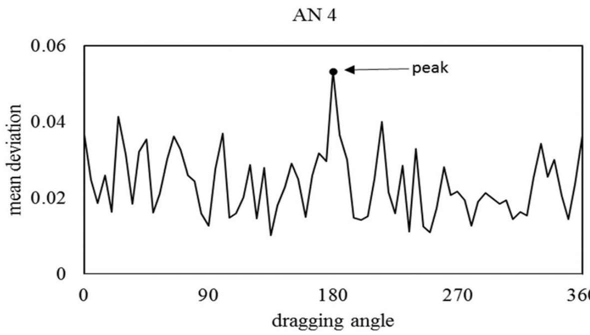
3.1 Stick-slip trace (SST) of friction coefficient and its mean deviation

Unlike woven fabric, there is no systematic construction in nonwoven fabric. However, each bonding method produces a specific geometric surface that influences the SST of the coefficient of friction and its mean deviation, μ_A trace. This section deals with the stick-slip trace of the coefficient of friction and its corresponding feature of mean deviation. If there were not any particular pattern on the surface of nonwoven, the coefficient of friction would show steady state pattern change. We called this steady pattern `regular SST' whose ranges were shown within dash-dotted lines in Fig. 5, Fig. 6 and Fig. 7. However, in this experiment, samples have some bonding patterns. Therefore, some irregularity might be occurred in their SST of coefficient of friction.

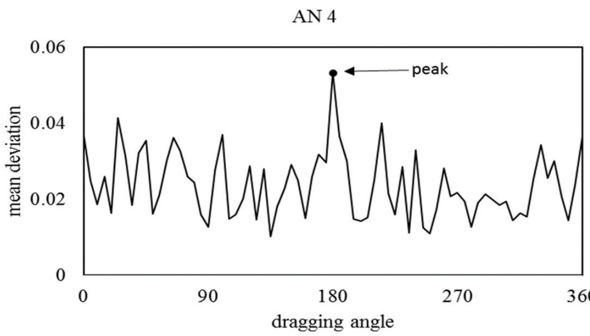
In minus-pattern bonding nonwovens, there is a



(a) Relationship between μ and θ (from 150° to 210°)

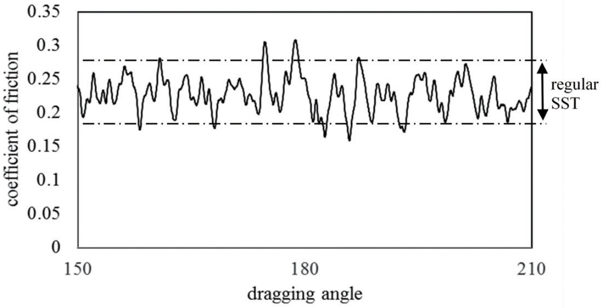


(b) Relationship between μ and θ (from 240° to 300°)

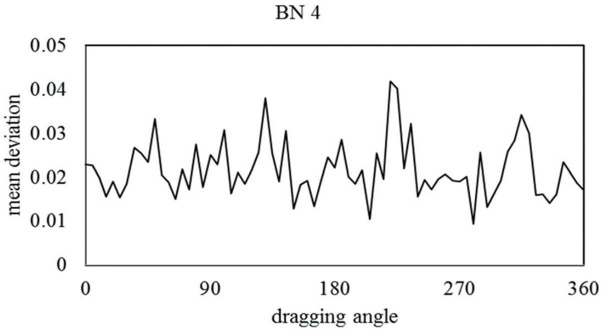


(c) Relationship between μ_A and θ (from 0° to 360°)

Fig. 5 Friction characteristics for minus-pattern (AN 4) spunbond



(a) Relationship between μ and θ (from 150° to 210°)

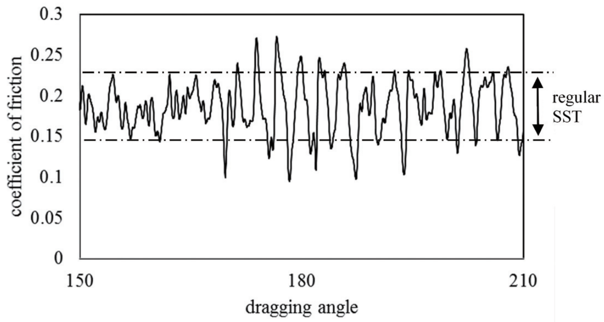


(b) Relationship between μ_A and θ (from 0° to 360°)

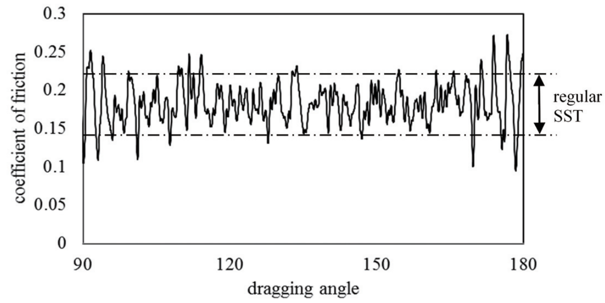
Fig. 6 Friction characteristics for point-pattern (BN 4) spunbond

knob between two adjacent bonding points. The higher the fabric weight, the more the knob protrudes. Most of the coefficients of friction show regular SST except around θ = 180° in Figure 5 (a) and (b). Its cause of the irregularity might be as following; the knob lifts the sensor wire up, and the bonding point causes the wire to drop. Hence, the vertical displacement of the sensor wire is higher at 180° than at other dragging angles. For that reason, higher value of μ_A was visually observed at a dragging angle of around 180° compared with other angles, as shown in Figure 5 (c). This higher value is identified as the peak value. This peak may also appear at 0° and 360° where the sensor wire travels across the bonding area.

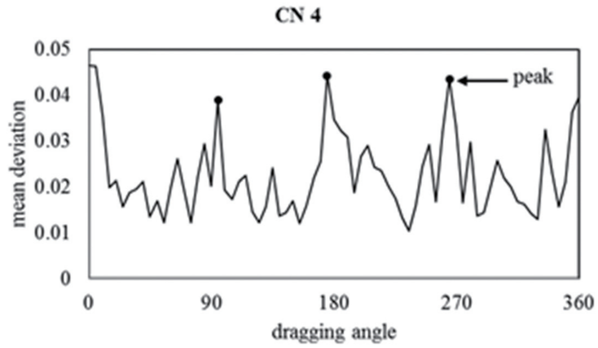
In point-pattern bonding nonwovens, most of the coefficients of friction show regular SST as indicated within dash-dotted lines in Figure 6 (a). The surface characteristics are the same in both MD and CD since small bonding points spread out across the entire surface. For that reason, the sensor wire meets component filaments that are exposed to the air more than the bonding points during testing. As a result, SST patterns affected by the oscillation motion of the sensor wire change almost regularly during the entire cycle, and the friction coefficient is regular in almost directions. The value of μ_A also change almost regularly at any directions. In other words, there is no clear characteristic in μ_A for point-pattern bonding nonwovens, as shown in Figure 6 (b).



(a) Relationship between μ and θ (from 150° to 210°)



(b) Relationship between μ and θ (from 90° to 180°)



(c) Relationship between μ_A and θ (from 0° to 360°)

Fig. 7 Friction characteristics for weave-pattern (CN 4) spunbond

In weave-pattern bonding nonwovens, the surface geometry looks like plain woven fabric. It is observed that the SST of the coefficient of friction changes similarly at every 90° of dragging angle except the angle where the sensor wire drags across the pattern. It might be caused the wire oscillating motion. Figure 7(a) shows SST around 180°. At other angles, irregularity in their coefficient of friction occurs as illustrated in Figure 7 (b). As a consequence, the peak value of μ_A appears at every 90° of trace angle, as shown in Figure 7 (c). However, the peak value at 90° and 270° is slightly lower than at 180°. This might be the result of changes in the direction of dragging from 0°–180° to 180°–360°.

These characteristics are not clear in thin-weight fabrics because the protrusions of unbonded areas on the fabric surface are extremely small.

3.2 Effect of fabric mass per unit area, bonding

method, and component filaments on coefficient of friction

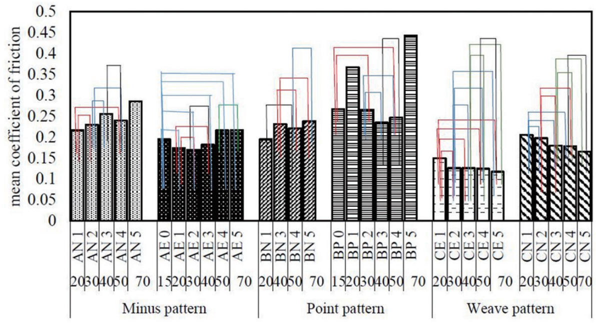
Since the factors affecting the frictional properties are complex, it is difficult to analyze these factors separately and theoretically. Thus, in this article, based on the experimental result, the varieties in the coefficient of friction of three kinds of spunbond nonwovens and possible influencing factors are discussed together.

SPSS statistic software was used to determine whether the fabric weight, bonding pattern, and component filaments significantly influence the frictional properties of spunbond nonwovens. The resultant ANOVA with the p-value is less than 0.05, and the R^2 value is 0.97 shown in Table 2 indicates that the selected model is suitable for determining the relationship between the dependent variable, mean coefficient of friction, and the independent variables, bonding pattern, component filaments and fabric weight. The factor with a p-value less than 0.05 has a significant impact on the mean coefficient of friction. The ANOVA result shows that the fabric mass per unit area, component filaments, bonding pattern, and all interactions between factors significantly affect on the friction coefficient.

A Scheffe test was carried to make multiple comparisons between different spunbond nonwovens. In Figures 8, 9 (a), and 9(b), the connecting lines between each pair of samples (represented by the bar graph) showed no significant difference.

In general, the coefficient of friction of minus and point-pattern bonding spunbonds decreased when the mass per unit area increased. Then, the coefficient of friction increased again. The reason is that the impact of surface architecture varies with the bonding methods in addition to the fabric density. Generally, the fabric surface is uneven at low weights, and a more even surface can be achieved with an increasing mass per unit area. On the other hand, an even surface develops only from one bonding point to the next. Since the bonding points cover about 15% and 11% of the total surface area in minus-pattern and point-pattern bonding nonwovens respectively, the unbonded points create a bulky and thick sheet that cause an additional resistance when the sensor wire is dragged across it. As a result, the coefficient of friction increased. By contrast, unlike minus-pattern bonding and point-pattern bonding nonwovens, weave- pattern bonding points cover almost 100% of the total surface, and hence a thin and paper-like surface appears with an increase in fabric weight. Generally, the value of the coefficient of friction decreased with a higher fabric density, and this tendency is true for nylon weave-pattern spunbond nonwovens. Nevertheless, there is no significant difference within polyester weave-pattern spunbond nonwovens. The results are shown in Figure 8.

Because of the aforementioned distinct surface characteristic of each bonded pattern, the friction coefficient of minus-pattern spunbond is the highest, followed by the point-pattern spunbond, and weave-pattern spunbond is the lowest for the same fabric density, and constituent filaments. But this tendency was not true in low-weight fabric. This might be the cause of the uneven surface area in low-weight fabrics. This result is shown in Figure 9 (a). For the same bonded pattern and fabric density, it is generally observed that the value of the friction coefficient of

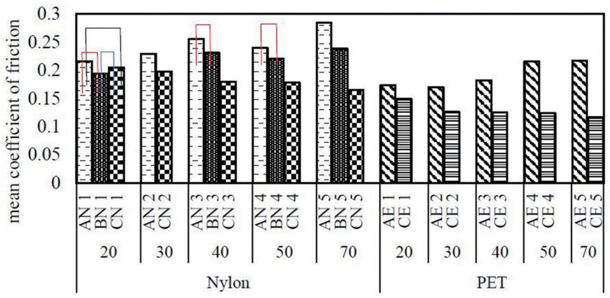


Note: The connection line between each pair of sample shows no significant difference

Fig. 8 Changes in mean coefficient of friction for different fabric weight

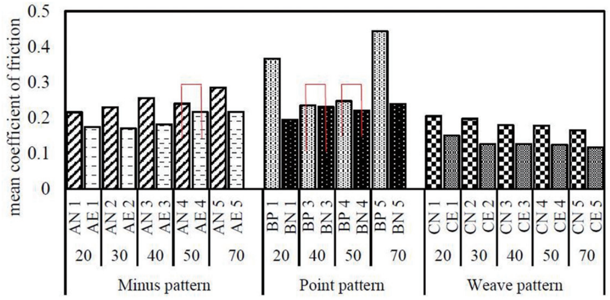
Table 2 ANOVA result

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.398[a]	30	0.047	411.945	0.00
Intercept	13.487	1	13.487	119228.850	0.00
weight	0.152	5	0.030	269.139	0.00
filament	0.353	2	0.176	1559.009	0.00
pattern	0.194	2	0.097	857.597	0.00
weight × filament	0.159	7	0.023	201.272	0.00
weight × pattern	0.055	7	0.008	69.288	0.00
weight × filament × pattern	0.006	4	0.001	12.497	0.00
a. R Squared = 0.978 (Adjusted R Squared = 0.976)					



Note: The connection line between each pair of sample shows no significant difference

(a) Effect of bonding pattern



Note: The connection line between each pair of sample shows no significant difference

(b) Effect of fiber material

Fig. 9 Mean friction coefficient of spunbond nonwoven samples

nylon spunbond is higher than that of polyester spunbond. Broadly, in point-pattern nonwovens, polypropylene spunbond has a higher coefficient of friction value than nylon spunbond. This result is illustrated in Figure 9 (b).

When a comparative study between KES and a whisker sensor machine was carried out, it was observed that there is a high correlation (0.9) for weave-pattern spunbond nonwovens. However, a low correlation is observed for minus and point-pattern spunbond nonwovens, with values of 0.62 and 0.42, respectively.

4. Conclusion

In this work, the frictional behavior of spunbond nonwoven fabrics was studied by using a simple whisker-type tactile sensor friction-testing machine. It was visually observed that the specific geometric surface of each bonding pattern influences the resultant stick-slip trace of the friction coefficient, and hence its mean deviation trace. The mean deviation of the friction coefficient is higher around 180° and around every 90° of dragging angle in minus-pattern bonding nonwovens and weave-pattern bonding nonwovens, respectively. However, the mean deviation value is almost the same for all directions in point-pattern bonding nonwovens. These phenomena indicate that the coefficient of friction of spunbond nonwovens varies in relative to the dragging direction and surface geometry. The ANOVA result confirmed that the bonding pattern, in addition to the fabric weight and constituent filament, have a significant impact on the frictional property of spunbond nonwovens.

Acknowledgement

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