DOCTORAL DISSERTATION

STUDY ON FRICTION PROPERTIES OF SPUNBOND NONWOVEN FABRICS

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CHAPTER 1
INTRODUCTION

It is clear that textile materials play a fundamental role in our daily life. Although clothing is the obvious textile industry, there are no sectors where textile is not related. Textile has been turning into an essential tool because of the development of modern textile industry such as automotive textiles, protective textiles, industrial textiles, construction textiles, medical textiles and miscellaneous textiles. Woven fabrics, knitted fabrics, and braiding and lace mainly concern with the clothing industry whereas utilization of nonwoven fabrics has increased sharply especially in industrial textiles, technical textiles, healthcare textiles and disposable textiles.

Among nonwoven production technologies, the spunbonding technique has been popular because of the continuous manufacturing process, time-saving and cost effective, and a high production rate. As consequences, a variety of spunbond production technique has been developed to achieve the unique quality of final goods. At the same time, quality control of spunbond nonwoven is important in term of specific end-use and peculiar performance.

On the other hand, friction property is one of the important properties since improvement of processing operation efficiency and the quality and performance of final products relate to the proper control of it. It has an impact on the total hand value of clothing textile. Therefore, there have been a number of investigations into the frictional behavior of textile hierarchy: fiber, yarn, and fabric.

Kawabata Evaluation System (KES) is one of the standard test methods and it has been widely used in Japan. In KES, the surface tester (KES-FB 4) is used to assess the frictional resistance in two directions, the machine direction (MD) and the crosswise direction (CD), of a fabric and the resultant value can be used in determining the total hand value of a sample. ASTM (American Society for Testing and Materials) method (IST 140.0-82) covers the determination of the coefficient of dynamic (kinetic) friction of a nonwoven textile when sliding over itself or a polished metal surface. An assembly of apparatus attached to a constant-rate-of speed-tensile tester achieves it [1]. Since friction is basically an energy dissipation mechanism, the friction value between the fabric and a sliding surface can be computed from the quality energy (QE) values [2].

Osman BABAARSLAN and Nazan AVCIOĞLU KALEBEK studied the friction coefficient of polypropylene spunbond nonwoven fabric with different weight by designing and manufacturing two different systems which work as a horizontal platform and inclined plane. They observed that high friction force becomes effective until a certain fabric weight and then a low friction force occurs because of a more stable structure. In addition, the coefficient of friction decreased when the applied load on the specimen increased. Because of the fiber/filament settlement at the fabric formation stage, friction coefficient in the machine direction (MD) is lower than that in the crosswise direction (CD) [3]. They also conducted a friction test on spunbond nonwovens under different loads and different friction environments (fabric-abrasive wool fabric, wood, and metal). It was observed that fabric-abrasive wool fabric friction generated negative affecting of surface characteristics and friction coefficient value whereas fabric-metal friction environment has less negative effect on friction surface and lowest friction coefficient. It was concluded that the applied force, fabric weight, rubbed surface, fabric directions, and fiber type are some impact factors of the friction behavior of fabrics [4].

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 [5]. X.Y. Wang and co-workers studied the frictional property of thermally bonded 3D nonwoven reported that the stick-slip trace 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 [6].

Friction is not an inbuilt property and comes out when textile to textile or textile to other surface drags over another. Therefore, both testing conditions and the material itself have an influence on it. Therefore, determination of friction is a complicated subject and it has been taking place as an interesting subject. There are plenty of investigations into the effects of testing conditions on fabric frictional property such as the applied normal load, the apparent contact areas, the sliding speed and the nature of contact surface. Further, many researchers focus on developing an accurate test method to determine the friction property of textile in easier and faster way.

These factors motivate the author to study the friction property of spunbond nonwoven fabrics by using an alternative method. The goal of this study is

1. to investigate the frictional property of spunbond nonwoven fabrics by using rotational dragging method
2. to determine the influencing factors on the friction coefficient of spunbond nonwoven fabrics
3. to examine the capability of rotational dragging method

A whisker-type tactile sensor rotational friction testing machine was used to accomplish this goal. The main merit of using it is to 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, Chapter (2) illustrates the basic principles of measuring friction property of textiles and factors affecting it. Chapter (3) deals with the construction and working principle of a simple whisker type rotational friction testing machine. In chapter (4), the stick-slip phenomenon (SSP) 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 was discussed. Chapter (5) concerns with the comparative study of friction property of selected spunbond nonwovens using KES-FB and rotational dragging method.

CHAPTER 2
BASIC PRINCIPLE OF MEASURING FRICTION IN TEXTILE

Since textiles are widely used as fabrics, the measurement, characterizing and understanding of their frictional behavior is important. The objective friction measurement system usually involves either a probe that can characterize a surface geometry or a probe that is designed to simulate human fingers assess friction of fabrics when a fabric is pulled against it. The former kind of measurement can often be related to fabric geometry, for instance, fabric sett, the spacing between cords, or ribs, etc. The latter method is influenced by not only the geometry of the fabric but also the material itself [5].

There are a large number of test methods in the evaluation of friction and these techniques are different from each other in term of the following facts [5].

i. the sort of contact between two sliding objects – point contact, line contact or area contact
ii. the environmental condition where the test is carried out - air, water or lubricant
iii. the type of textile used - fiber, yarn or fabric including woven, knitted or nonwoven
iv. the relative movement of the test method - how to apply the normal load and measure the friction force.

The sort of contact used during measurement correlates with the nature of contacts found in textiles during processing and use. For instance, point contacts exist between needle and fibers during needle punching in the manufacturing of nonwoven. The line contact may exist between fibers during drafting in yarn formation. Between clothing and skin, clothing and upholstery are the examples of surface contact [5].

2.1. The Concept of Friction of Fibrous Materials

During the latter half of the twentieth century, studies have shown that the coefficient of friction of natural and synthetic fibers is not a material property, but is a function of the normal force and the geometric area of contact. When the normal force increases, the coefficient of friction decreases. The fiber size, the surface smoothness and the mode of contact (point, line or area) also affect the friction coefficient value. In the classical materials (metals), the friction force is directly proportional to the normal force, known as Amonton's law. However, friction in textiles fails to obey this law because of its viscoelastic nature and the nonlinear relation occurs with most polymeric materials. The simplest and the most widely accepted of this relation can express as the followings: [5]

$F = aN^n$ (with F and N in the unit of force, N) ……… (2.1)

$F = a' N^n$ (with F and N in the unit of stress, Pa) ………… (2.2) where n = empirical constant

a = empirical constant with the unit of $(N)^{1-n}$

a' = empirical constant with the unit of $(Pa)^{1-n}$

F = friction force with the unit of either N or Pa

N = normal force with the unit of either N or Pa

If the tests are of a filament or a yarn, the value of F and N used are in the unit of force (N) and the F and N values are more appropriate in the unit of stress (Pa) if the test involves fabrics.

Nevertheless, in friction tests of textile materials where the normal force is usually maintained constant, the primary parameter assessed is still the coefficient of friction, μ. On contrary, in the case of interesting in the characterizing the behavior of the material, the values of the empirical constant are found by the conduction of friction force at several values of normal force and the data of logarithm of F is fitted against the logarithm of N by the least square method. The value of n is close to unity (0.7-0.9) whereas the value of a is similar to the value of a classical parameter, μ [5].

2.2. Basic Principle of Measuring Fabric Friction

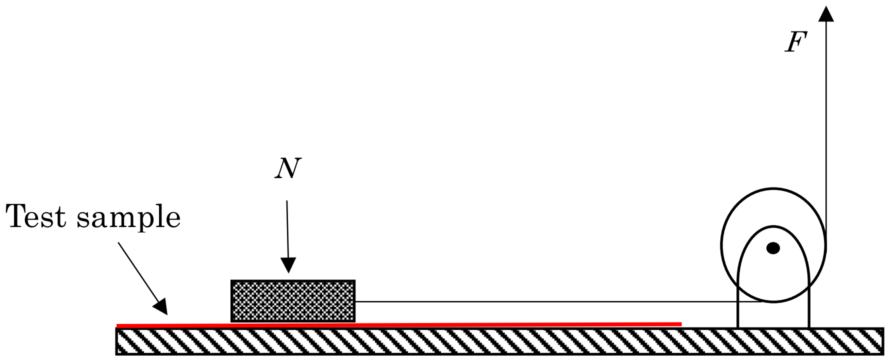


Figure 2.1. Horizontal plane principle

Generally, there are two basic principles to measure fabric friction. The first one is the horizontal plane principle and the second one is the inclined plane principle. The schematic diagrams of these principles are shown in Figure 2.1 and 2.2, respectively. In the horizontal plane principle, a block of mass m is pulled over a flat surface where the sample is rest. The line fastened to the block is connected to the load cell in a tensile testing machine through a frictionless pulley. The load cell can measure both the static friction force, F_s, required to start the block, and kinetic friction force, F_k, required to keep moving the block. Then, the coefficient of static friction and kinetic friction are calculated from the following equation [7].

$$\text{coefficient of friciton}, \mu = \frac{F}{N} = \frac{F}{mg} \quad \ldots\ldots\ldots \ldots\ldots\ldots(2.3)$$

Since the friction force comes out when two materials are in contact and drag against each other, the known material such as wood or steel should be used as a block. Sometimes, the block covered with standard fabric or fabric as same as the sample is used in order to know the friction property between fabrics. Fabric finishes, for instance, applying softeners, is one of the factors that can also change the value of friction coefficient [7].

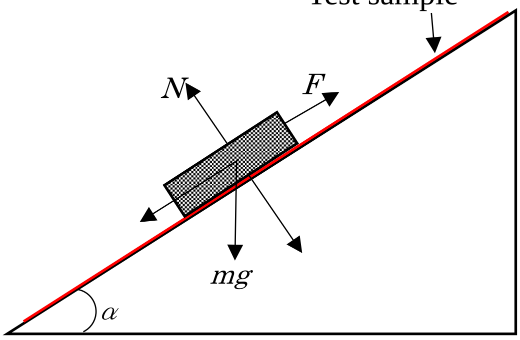


Figure 2.2. Inclined plane principle

In the inclined plane principle, the block of mass m rests on the inclined plane where the test sample is rest. When testing, the inclined plane angle, α is increased gradually until the block just begins to slide. At this point, the friction force and normal force can be expressed as the following equations [7].

$$F = mg \sin \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

$$N = mg \cos \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

Therefore,

$$\text{coefficient of friction, } \mu_s = \frac{mg \sin \alpha}{mg \cos \alpha} = \tan \alpha \quad \ldots\ldots\ldots (2.6)$$

By determining the minimum angle at which motion of block continues, the dynamic coefficient of friction can be evaluated by using equation (2.6) [7].

2.3. Kawabata Evaluation System (KES)

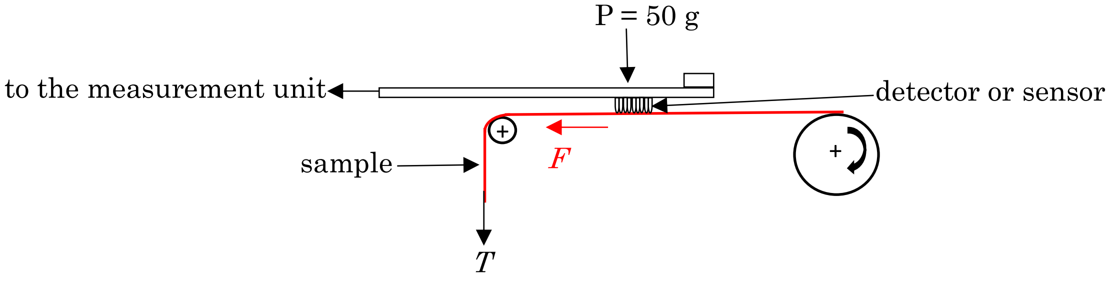


Figure 2.3. Kawabata surface friction tester

KES is the standard test method to measure the mechanical properties of fabric objectively and from which the fabric handle value is calculated. This system includes four different machines by which tensile, shear, pure bending, compression, and surface friction and roughness of fabric are examined. The average friction coefficient, deviation of average friction coefficient and surface roughness can achieve with the surface tester. Figure 2.3 shows the systematic diagram of surface friction tester. Ten piano wires with 0.5 mm in diameter and 5 mm in length are used as a detector and it simulates finger skin geometry.

2.4. Standard Friction Test for Nonwovens

Friction test method used for fibers, so-called staple pad friction test, can be available for measuring friction of nonwovens fabrics. In this method, a pad of staple fibers is placed on the horizontal platform and over which a sled of 10 or 20 N is placed. Then, this platform is fitted on the tensile tester and the sled is dragged by mean of the tensile tester cross head. The platform should cover with sand paper in order to avoid slippage between a sample and solid surface. Testing speed is kept low to improve test resolution. This method is shown in Figure 2.4. INDA (International Nonwovens and Disposables Association) standard test method is also available for measuring friction of nonwovens [5].

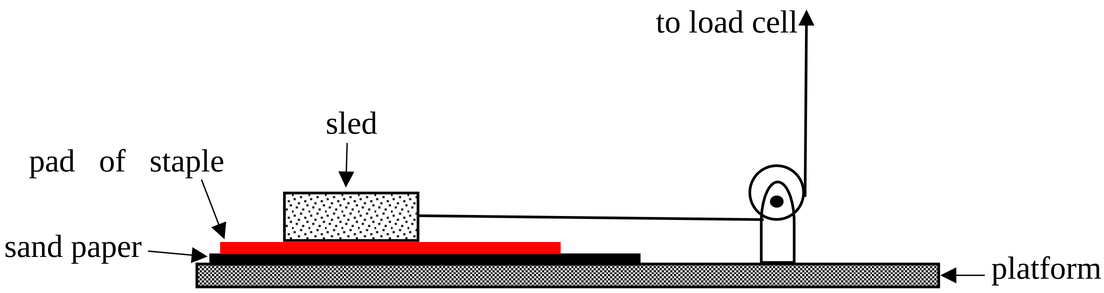


Figure 2.4. Staple pad method

2.5. Stick-slip Phenomena (SSP) in Friction Test

The nature of plot of force against time is typically stick-slip in nature, which reflects a characteristic of most materials. Since the frictional resistance of textile materials is governed by many variables, the prediction of friction and SSP is still very difficult. In general, the stick-slip pattern is more prominent as the material is softer and more viscose-elastic. In yarn and fabric state, the structure, surface morphology or roughness and bulk properties may influence the fluctuations of stick-slip trace [5].

This stick-slip motion has been classified into two forms, the regular and irregular stick-slip traces. It is observed that smooth surfaces generally yield low frictional resistance and amplitude of stick-slip pulses. The number of stick-slip pulses is usually high in a regular trace and low in an irregular trace. Rough surfaces usually lead to larger frictional resistance and lower pulse frequency [5].

To produce stick-slip phenomena, the following basic conditions should meet [5].

i. The value of static coefficient of friction is larger than that of kinetic friction.

ii. The system is flexible enough to enable a change in the speed of the sliding body.

In general, the contribution to SSP can arise in contacting materials from different levels of organization within the structure: [5]

iii. Nano-level – due to bonds and forces between particles (atoms, molecules, etc.).

iv. Micro-level – due to surface morphology of fibers.

v. Macro-level – geometries of assemblies (yarn and fabric).

vi. Environmental level – due to the influence of air, moisture, finish at the surface.

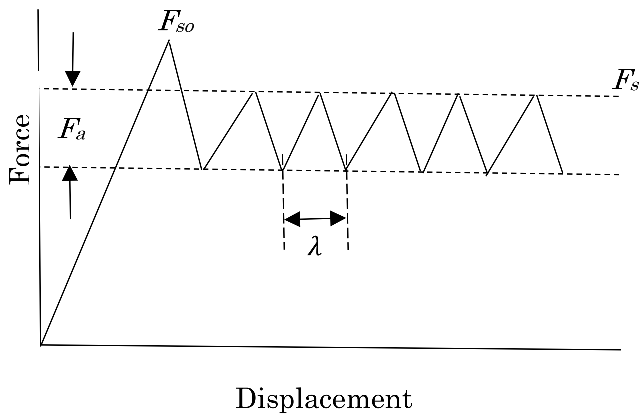


Figure 2.5. Hypothetical friction trace for a textile material

Figure 2.5 represents the hypothetical friction trace for a textile material. Generally, the force at the first instance of sliding is the highest value of the force and after that, the force oscillates between peaks (registered at the instant of slip) and troughs (registered at the instant of sticks) whose values are lower than the first peak. The following parameters are used to characterize a friction profile: [5]

(i) The static friction force F_{so} that corresponds to the first peak in the profile.

(ii) The static friction resistance F_s, which represents the mean of peaks excluding the first peak.

(iii) The kinetic friction resistance F_k, which is the average value of the peaks and the troughs or the average value of the force. This force will be equal $F_s - 0.5\ F_a$.

(iv) The amplitude of frictional resistance F_a, which is the average height of the stick-slip pulses, excluding the first peak.

(v) The frequency of peak F_f, which represents the average number of peaks per unit length of the traverse. This is equal to λ^{-1} where λ is the average wavelength of the fluctuations.

(vi) The number of peaks/unit length F_n, and

(vii) The difference $F_s - F_k$.

These parameters describe the complete surface topography and are well correlated with the tactile sensations of smoothness, scroopiness, softness, roughness, and rigidness normally felt on fabric surfaces. In parallel with the characterization of a stick slip profile, it will be useful to also characterize the topography of a fabric using a geometric model [5].

2.6. Factors Affecting on Friction

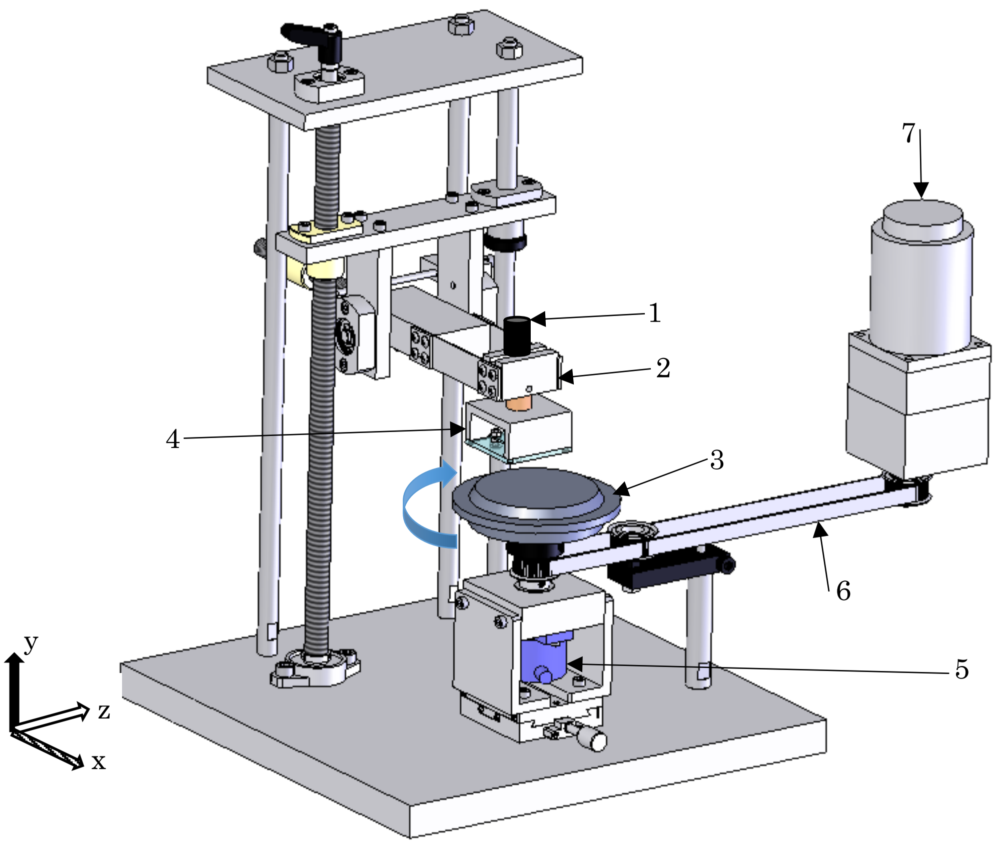
Some important factors effect on the frictional values are as follows: [5]

i. the nature of contactor (line, point or area contact)
ii. the morphology of the surface (degree of roughness or smoothness)
iii. the magnitude of normal force
iv. the sliding speed
v. the environment along the contact region
vi. the mechanical behavior of junctions
vii. the numbers of asperities in contact
viii. the testing environment (temperature and relative humidity)
ix. The time of contact (time before sliding and speed of sliding)
x. The number of traverses

CHAPTER 3
WHISKER TYPE TACTILE SENSOR FRICTION TESTING MACHINE

There are many methods for testing friction property of fabrics, nowadays. In this study, a simple whisker type tactile sensor friction testing machine which entitles the coefficient of friction between the fabric surface and sensor wire by rotational dragging. This machine can measure the friction and tangential force precisely from the resultant strain caused by both normal and shear deformation. Hence, the friction coefficient of woven and nonwoven fabrics can be calculated. The construction and working principle of this machine were discussed in this chapter.

3.1. The Whisker Type Tactile Sensor Friction Testing Machine



1.Vertical load 3. Sample stage 5. An encoder 7. Motor
2. Load cell 4. Whisker sensor unit 6. Belt

Figure 3.1. Whisker type tactile sensor friction testing machine

The schematic illustration of this machine is shown in Figure 3.1 and the block diagram of this machine is illustrated in Figure 3.2. This machine based on the rotational dragging method. It has mainly consisted of the following units. They are

i. the tactile sensor unit
ii. sample stage
iii. an encoder
iv. the speed control motor and speed controller
v. the data acquisition system

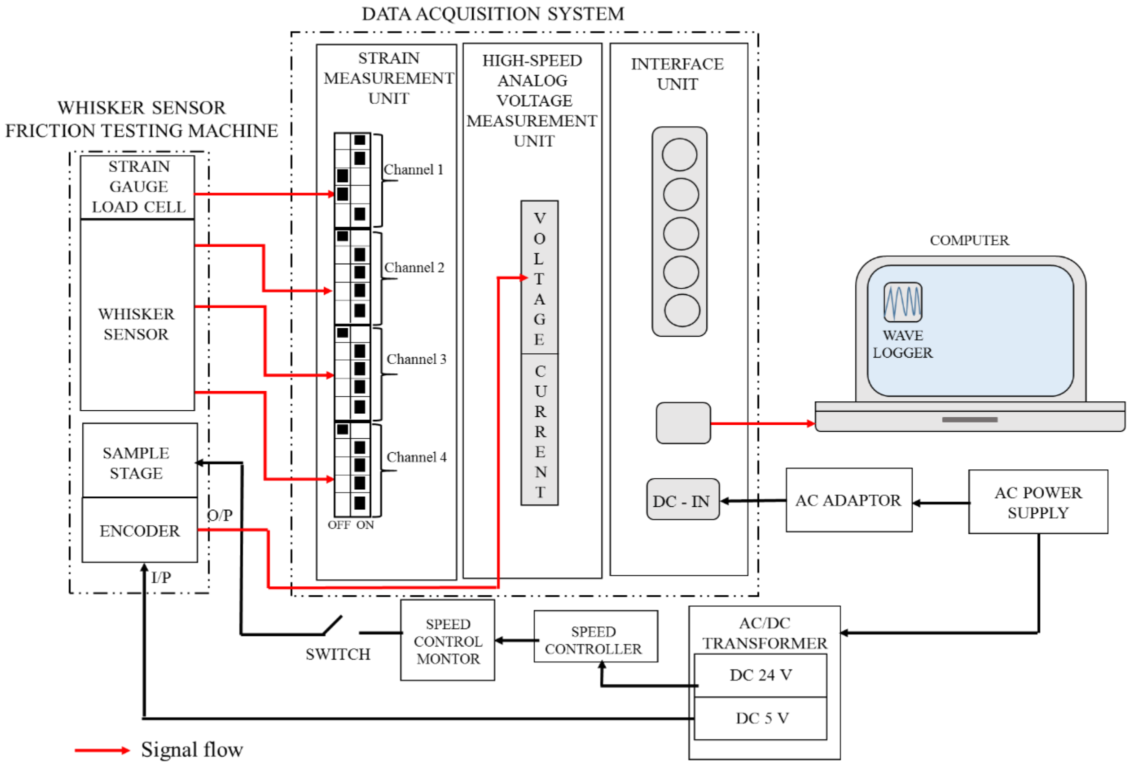
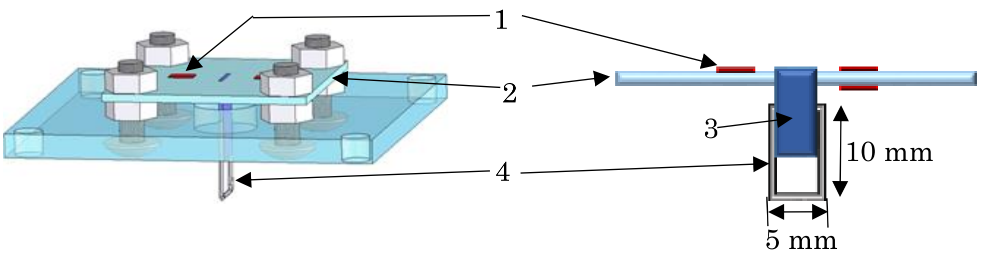


Figure 3.2. Block diagram of whisker type tactile sensor friction testing machine

3.1.1. The tactile sensor unit



1. Strain gauge 2. Base (acrylic plate) 3. Acrylic plate 4. Sensor wire

Figure 3.3. Whisker sensor unit

The whisker sensor unit or sensor head is the heart of the machine and Figure 3.3 illustrates the schematic diagram of it. It consists of an acrylic-based plate (25×25 mm^2) on which three strain gauges are pasted and the sensor wire or piano wire is also attached to this plate through a piece of an acrylic plate (10×5 mm^2). The piano wire, 0.5 mm in diameter, is used in making sensor wire [8, 9].

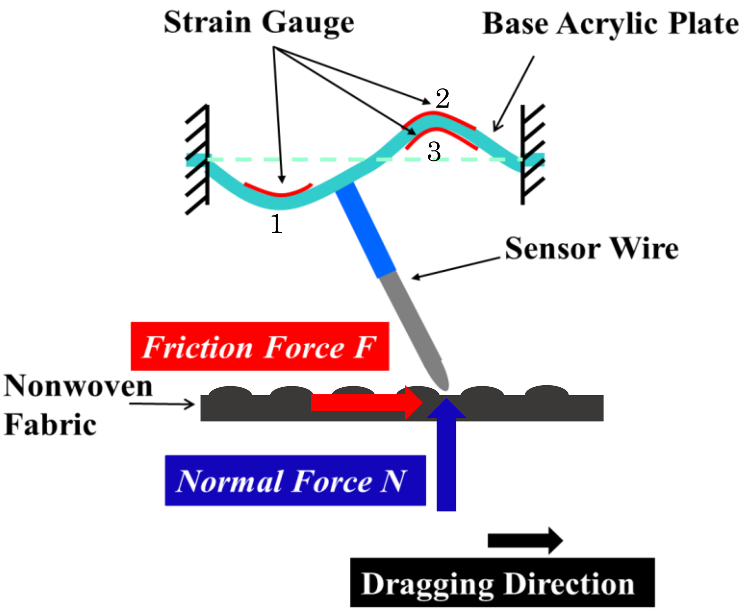


Figure 3.4. The working principle of sensor

Figure 3.4 represents the working principle of the tactile sensor. As the result of the compressive force and friction force exerted on the sensor wire, the strain occurred on the base acrylic plate and also the strain gauges. Since each strain gauge is in the strain measurement device, the resultant total strain can be detected by measuring the output signal. Hence, the exerted friction and normal force are calculated. In this machine, these two forces are detected by three channels.

3.1.2. The rotation sample stage

The sample stage rotates on its own axis in the y direction and on which the tested sample is rested with an iron ring and clippers. The diameter of rotation stage is 75 mm and the speed of it is 0.5 revolution per minute.

3.1.3. An encoder

An incremental rotary encoder fitted under the sample stage is used to determine the position of the sample stage. The resolution is 1,000 pulses and it is connected to the high speed analog voltage measurement unit of data acquisition system. Therefore, the coefficient of friction at each and every degree of sample stage can be achieved.

3.1.4. The speed control motor and speed controller

The servo motor and speed controller are used for getting the determined constant sample stage speed. This speed can also change by adjusting the speed controller.

3.1.5. The data acquisition system

High-speed sampling data acquisition system together with the wave logger software is used in acquiring signals from tactile sensor and encoder simultaneously. High-speed analog voltage measurement unit, strain measurement unit, and interface unit are composed of this measurement unit. Strain measurement unit is built-in bridge box and it can connect the strain gauge and load cell directly. To overcome the influence of noise, low pass filter is setup in strain measurement unit and differential input method is used in analog voltage measurement unit. In order to improve the measurement accuracy, the power supply should turn on 30 minutes earlier before testing and calibration of this data acquisition system should carry out once a year.

3.2. The Operation

The rotationally dragging tactile sensor can measure the friction coefficients of nonwoven fabrics surfaces continuously without regarding the specific directions, machine direction (MD) or crosswise direction (CD). The tested sample in the size of 12×12 cm^2 was placed on the sample stage with an aid of an iron ring and clippers. When the desired weight is applied to the load cell, the sensor wire is brought into contact with the sample surface and trust into it. The friction force is being generated between the fabric and sensor wire under the influence of normal force while the sample stage is keep moving. These two forces are transmitted to base acrylic plate and resulting in strain on three strain gauges. As a result, strain occurs on the base acrylic plate and at the same time, on strain gauges. Because strain gauges are in the Wheatstone bridge, the output voltage is directly proportional to the strain caused by two forces. The resultant total strain is recorded with data acquisition system and wave logger software. At the same time, the encoder detects the position of the sample stage. By this means, the coefficient of friction value against rotational angle is achieved by taking the ratio of friction force and normal force. The data is recorded at every 0.3 seconds. The rotation radius of the sensor is 20 mm and its velocity is 1 mm/sec [8, 9].

3.3. Measuring Method of Dynamic Coefficient of Friction

Strain occurred in an elastic deformation range is the sum of total deformation caused by friction forces, normal force and the changes in temperature. Base on this theory, the total strain on the tactile sensor calculated as follow [8, 9].

$$strain\ (ST) = measured\ value(\mu ST) \times\ 10^{-6} \times \frac{2}{gage\ factor} \quad \ldots\ldots(3.1)$$

where, gauge factor = 2.05

And strain gauge output strain

$$\varepsilon_1 = a_1 N + b_1 F + c_1 T \quad \text{.......(3.2)}$$

$$\varepsilon_2 = a_2 N + b_2 F + c_2 T \quad \text{.......(3.3)}$$

$$\varepsilon_1 = a_3 N + b_3 F + c_3 T \quad \text{.......(3.4)}$$

where, $N =$ the normal force

$F =$ the friction force

$T =$ the temperature

$a_1, a_2, a_3 =$ the proportional constant for the normal force

$b_1, b_2, b_3 =$ the proportional constant for the friction force

$c_1, c_2, c_3 =$ the proportional constant for the temperature

Hence, the influence of temperature is assumed to be slight.

So, $c_1 = c_2 = c_3$.

The strain gauge 1 that compresses because of normal force and strain gauge 3 that expenses because of normal force are used. Therefore, from equations (3.2) and (3.4), the normal force is calculated as the followings.

$$N = \frac{b_3\varepsilon_1 - b_1\varepsilon_3}{a_1 b_3 - b_1 a_3} \quad \text{......(3.5)}$$

To simplify, $a_1 = -a_3 = a$ and $b_1 = b_3 = b$. Hence,

$$N = \frac{\varepsilon_1 - \varepsilon_3}{2a} \quad \text{..........(3.6)}$$

The strain gauge 1 that compresses because of friction force and strain gauge 2 that expenses because of friction force are used. Therefore, from equations (3.2) and (3.3), the friction force is calculated as the followings.

$$F = \frac{-a_2\varepsilon_1 + a_1\varepsilon_2}{a_1 b_2 - b_1 a_2} \quad \text{......(3.7)}$$

To simplify, $a_1 = a_2 = a$ and $b_1 = -b_2 = b$. Hence,

$$F = \frac{\varepsilon_1 - \varepsilon_2}{2b} \quad \text{.........(3.8)}$$

From equations (3.5) and (3.7), the coefficient of friction is calculated as the followings.

$$\mu = \frac{F}{N} \quad \text{.................(3.9)}$$

3.4. Calibration Experiment

In order to maintain instrument accuracy, both load cell and tactile sensor calibration carried out at a certain period. Figure 3.5 and 3.6 (a) and (b) show the resultant calibration graphs of the load cell and sensor respectively. Hence, the calibration coefficient of normal force and friction force were calculated.

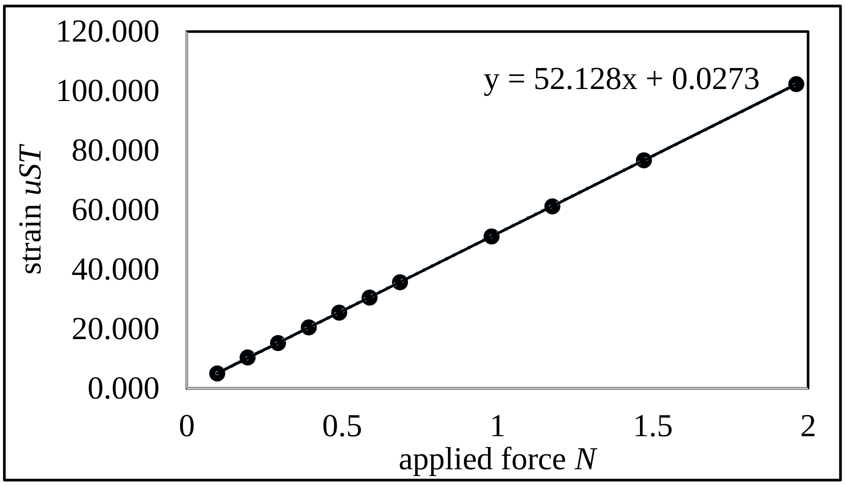


Figure 3.5. Load cell calibration result

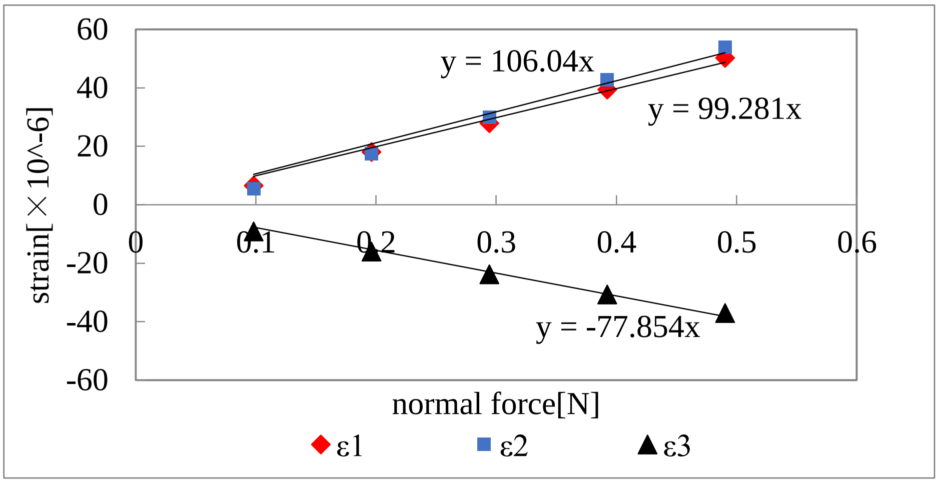


Figure 3.6. (a) Tactile sensor calibration (Normal force)

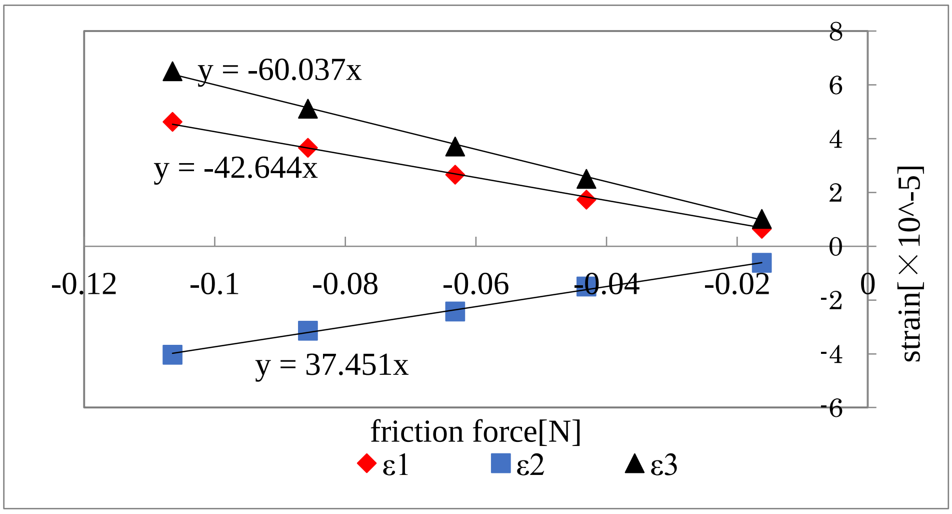


Figure 3.6. (b) Tactile sensor calibration (Friction force)

From calibration experiment, the calibration coefficient of friction force and normal force are as the following:

a_1 = 0.00009928 a_2 = 0.00010604 a_3 = - 0.00007785

b_1 = - 0.00060037 b_2 = - 0.00042644 b_3 = 0.00037451

3.5. Friction Characteristics Values

In order to evaluate the geometric characteristics of the surface of the test sample from an evaluation of friction, the value of mean dynamic friction coefficient and mean deviation are computed. Ten readings were taken for each sample and the average dynamic friction coefficient is calculated by averaging 10 times data. Then, the mean value of friction coefficient is achieved by averaging every 5 ° of dragging angle. This value represents a change in coefficient of friction of the fabric surface according to the dragging angle. Moreover, mean deviation of the coefficient of friction is calculated by averaging every 5° of dragging angle. Mean deviation represents the dispersion of the dynamic coefficient of friction and it relates to the position of the sample and vertical displacement of sensor wire during dragging.

The following formulae show how to calculate the value of mean dynamic friction coefficient and mean deviation.

Mean coefficient of dynamic friction, $\overline{\mu} = \frac{1}{n} \sum_{i=1}^{n} \mu_i$ ……. (3.10)

Mean deviation, $\mu_A = \frac{\sum_{i=1}^{n} \mu_{Ai}}{n}$ ……… (3.11)

where , n = the number of dynamic friction in every 5°.

3.6. The Difficulty of Measuring Coefficient of Friction

Since the value of friction force in this study is too low, the corresponding measurement uncertainty is a big concern. In this study, sometimes the steadily lower or higher stick-slip trace of the mean dynamic coefficient of friction was observed. This might also be a very small misalignment of load cell axis relative to the sample stage and/or deflection of sample stage axis relative to its own rotation axis. In order to overcome this unwanted errors, calibration of the load cell and whisker sensor should do at a certain period.

CHAPTER 4
FRICTION PROPERTIES OF SPUNBOND NONWOVEN FABRICS

Nowadays, as the increasing usage of spunbond nonwoven fabrics in diverse sectors, for instance, using in civil engineering as geotextiles, applying in health care sector as medical textiles and disposal textiles, decorating in car interior as mobile textiles, achieving in the unique structure and properties for specific usage becomes a compulsory subject. Since friction is one of the quality-related properties that can determine the degree of fabric smoothness and comfort and it can also be used for prediction fabric mechanical properties, an accurate, easy and quick method of measuring friction property of fabric has become an essential tool.

There are hundreds of researches on the friction property of nonwovens, however, most of them emphasized on the effect of testing parameters such as normal force and sliding speed on the friction force. In addition, most of the friction testing principle base on the surface contact and measurement in two directions, machine direction (MD) and crosswise directions (CD) of a sample surface was needed. On the other hand, frictional properties of spunbond nonwovens is influenced by the material properties, for instance, bonding method. Therefore, the influence of material properties such as fabric density, consisting filament and bonding pattern on the frictional resistance of spunbond nonwoven fabrics was investigated in this chapter. Moreover, rotational dragging method was used in order to know the frictional resistance in all directions. The advantage of using rotational dragging method is the coefficient of friction of sample can measure without regarding the specific direction (MD and CD) within a short period. SPSS (Statistical Package for the Social Sciences) software was used in analyzing the resultant data statistically. Additionally, the stick-slip phenomenon (SSP) of each type of spunbond nonwovens against dragging angle at micro level was studied in this chapter.

4.1. Spunbond Nonwovens Fabric

The spunbond nonwoven fabric is produced by spunbond process that includes extrusion of filaments from molten polymer solution through spinnerets, drawing into continuous filaments and disposition of filaments (web laying), thermo-compressive bonding of evenly distributed filaments web passing through a pair of embossing roll and winding a bonded sheet into roll goods. In bonding zone, the webs pass between the engraved roller and the smooth roller resulting a spunbond embossed with the pattern only one side while the other side remains smooth. Figure 4.1 and Figure 4.2 illustrate the flow diagram and production line of spunbond process.

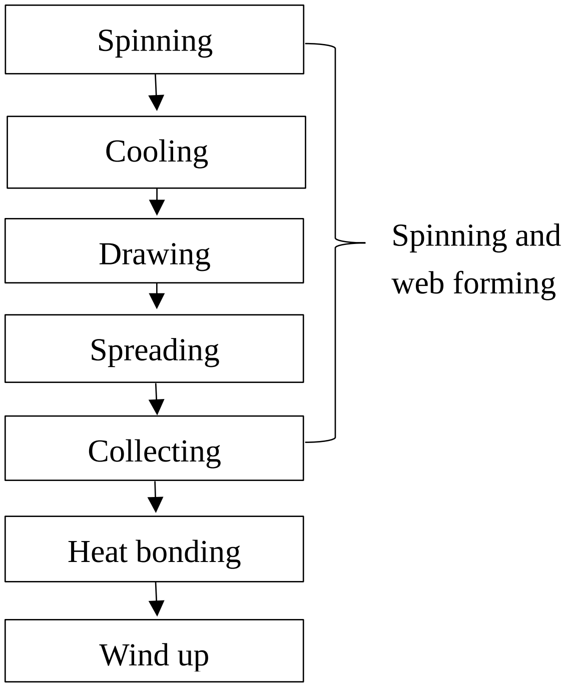
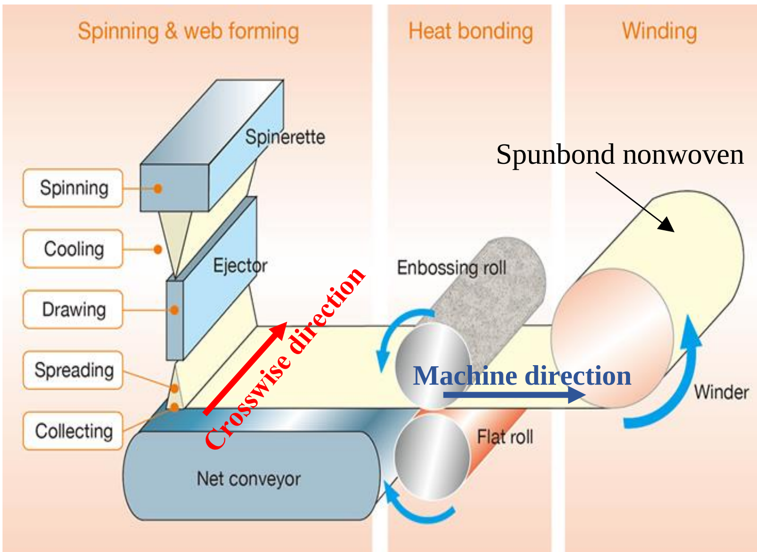


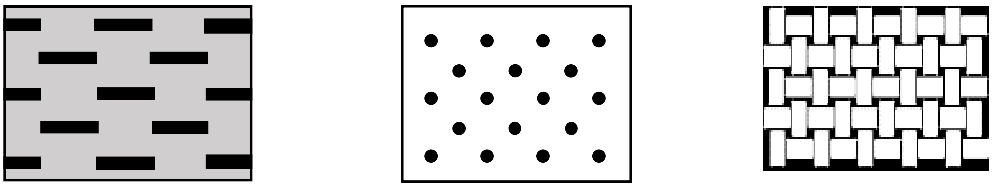
Figure 4.1. Flow diagram of spunbond process



**Source: http://www.asahi-kasei.co.jp*

Figure 4.2. Production line of spunbond process

In this study, commercial spunbond nonwoven fabrics produced from Asahi Kasei Co.Ltd., were used. They are made from a sheet of web in which synthetic long filaments are uniformly distributed and are bonded by thermocompression. No adhesive is used for bonding. In other words, they are self-bonded nonwovens. Spunbond nonwoven fabrics are composed of nylon, polyester (PET) and polypropylene (PP) filaments and bonded by three different patterns, minus pattern, point pattern and weave pattern. Each kind of filament has own characteristics. Nylon has a soft texture, good drape, and high strength. It′ s dyeability and processability is also great. Polypropylene has light-weight, high-volume, and high-bulk features. It has superior lipophilic properties and good heat processability. Polyester filaments have great dimensional stability, good heat, and light resistance. Because of having high strength, its processability is good. Further, each type of bonding method gives a distinct geometric surface. Figure 4.3 illustrates the schematic diagram of bonding patterns.



Minus pattern Point pattern Weave pattern

Figure 4.3. Bonding patterns

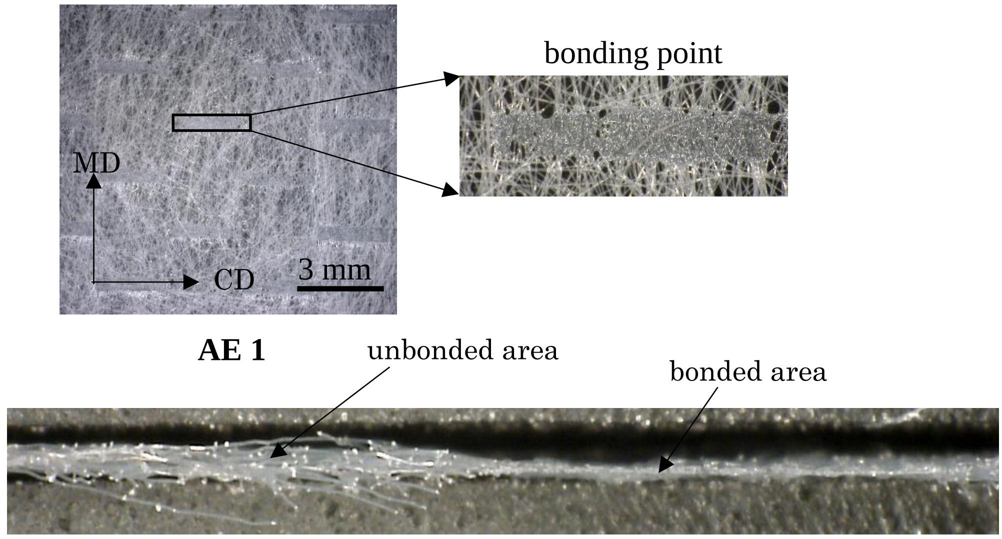
Based on these material characteristics and other relative producing process parameters such as bonding pattern, bonding temperature and bonding time, the resultant spunbond nonwovens are soft to hard and some are alike as paper. These parameters influence the final bonded web properties by somehow.

4.1.1. Minus-pattern bonding nonwoven

In minus pattern bonding, each and single bonding area surrounded by the non-bonding area appears minus sign. Each bonding points is approximately 2.5 mm in length and 0.5 mm in width. In the bonding area, the filaments deformed because of thermal compression whereas those of unbonding area are free. In the low weight fabric, the surface is more open and uneven compared to the high weight fabric. Although an even surface was achieved with an increase in fabric weight, this evenness observed from one bonding point to the next and as a result, the area between two bonding points protrudes as a knob on the surface and which can be seen clearly in high weight fabric.

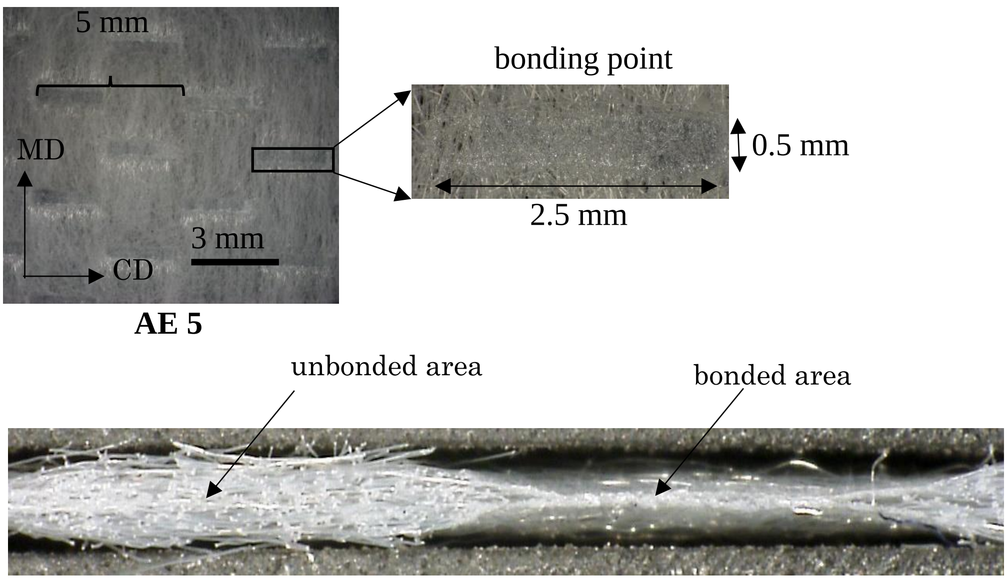
In this fabric, the length of the pattern is perpendicular to the machine direction (MD) and it is parallel to cross-direction (CD) of the nonwoven. The bonding area covers about 15% of the total surface area and bonding density is 80 points per unit area of 1 inch. The bonding points are uniformly distributed throughout the entire surface. Figure 4.4 (a) and (b) show the SEM images of polyester spunbond nonwovens.

In this study, polyester and nylon spun-webs bonded with minus pattern were evaluated. Even the bonding pattern is the same, the resultant fabric characteristics differ correspond with the constituents filaments. Nylon spunbond nonwoven looks like fabric whereas polyester spunbond nonwoven is alike as paper.



(filament: PET, fabric density: 20g/m^2)

Figure 4.4 (a) SEM image (25X), bonding point (100X) and through-thickness image (50X) of minus pattern spunbond

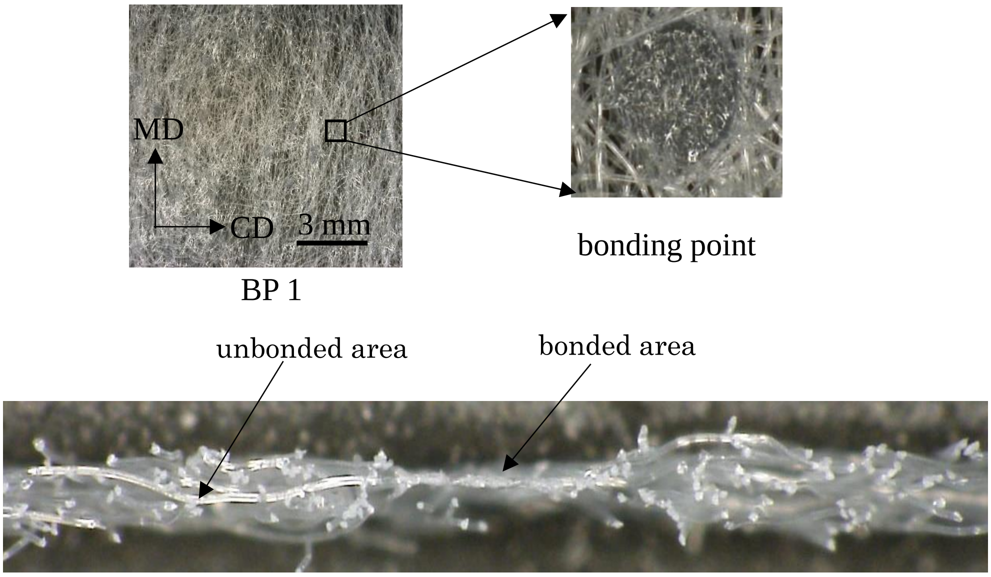


(filament: PET, fabric density: 50 g/m^2)

Figure 4.4 (b) SEM image (25X), bonding point (100X) and through-thickness image (50X) of minus pattern spunbond

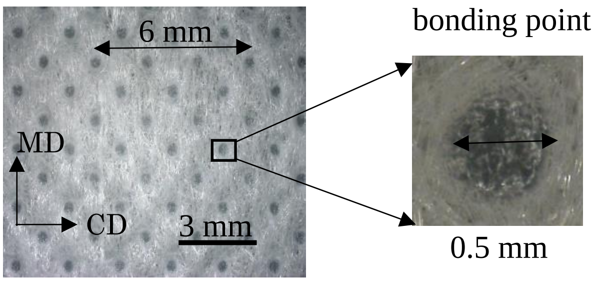
4.1.2. Point-pattern bonding nonwoven

In point pattern bonding, the 0.5 mm diameter circular points are distributed evenly through the surface. The bonding points cover approximately 11% of the entire surface and the bonding density is 300 points per unit area of 1 inch. Therefore, an almost entire portion of the filaments appear on a surface and resulting in a lofty nonwoven. The point-pattern spunbond nonwoven is thicker and more loft than minus-pattern and weave-pattern spunbond nonwovens, in the case of same mass per unit area and component filaments. In the thin fabric, the loftiness of the surface is not clear but the thicker the fabric, the more loft the nonwoven. Figure 4.5 (a) and (b) show the SEM images of polyester spunbond nonwovens. In this study, nylon and polypropylene point-pattern spunbond nonwovens were investigated. Like minus-pattern spunbond nonwoven, the higher the fabric weight, the clearer the pattern. The geometric structure in both MD and CD are the same.

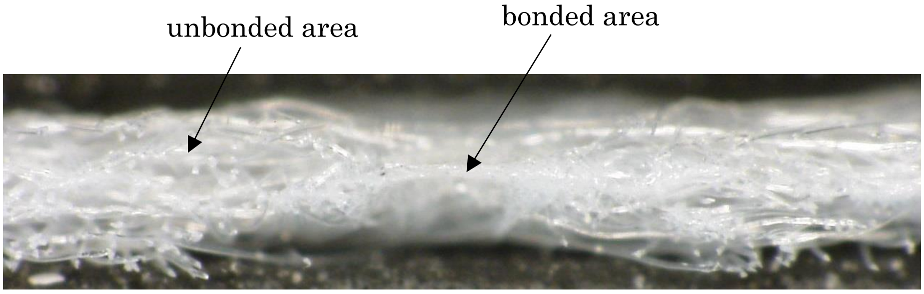


(filament: PP, fabric density: 20g/m^2)

Figure 4.5 (a) SEM image (25X), bonding point (100X) and through-thickness image (100X) of point pattern spunbond



BP 5

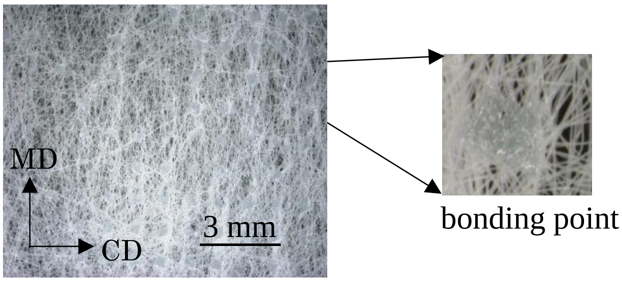


(filament: PP, fabric density: 50g/m^2)

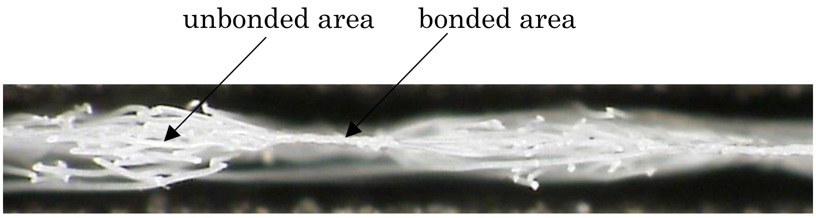
Figure 4.5 (b) SEM image (25X), bonding point (100X) and through-thickness image (100X) of point pattern spunbond

4.1.3. Weave-pattern bonding nonwoven

The surface pattern of the weave-pattern spunbond nonwoven is similar to the interlacing of warp and weft. The bonding points appear as a small square and the bonding density is 625 points per square area of 1 inch and the bonding points covers throughout the entire surface. Because of the difference in producing method parameters and components filaments properties, nylon weave bonding pattern nonwoven has more draperies compared to polyester spunbond which is thin, stiff and paper-like spunbond. In the case of same fabric density and consisting filaments, the weave-pattern spunbond nonwoven is thinner than minus and point-pattern spunbond nonwovens. The geometric structure in both MD and CD are the same. In all three bonding method, an even surface achieves with increasing mass per unit area. Figure 4.6 (a) and (b) show the SEM images of polyester spunbond nonwovens.

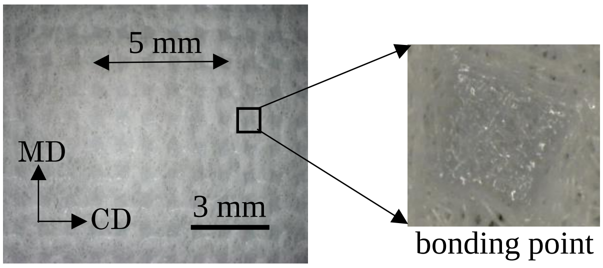


CN 1

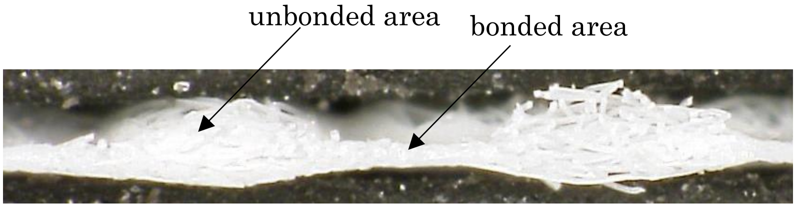


(filament: Nylon, fabric density: 20g/m^2)

Figure 4.6 (a) SEM image (25X), bonding point (100X) and through-thickness image (100X) of weave pattern spunbond



CN 5



(filament: Nylon, fabric density: 50g/m^2)

Figure 4.6 (b) SEM image (25X), bonding point (100X) and through-thickness image (100X) of weave pattern spunbond

4.1.4. Usage of spunbond nonwoven fabrics

The usage of spunbond nonwovens has increased sharply not only in durable textiles but also in disposable applications. The test samples are used in the following areas:

i. Industrial materials
ii. Building materials
iii. Agricultural materials
iv. Interior bedding
v. Household miscellaneous goods
vi. Automotive materials
vii. Various kinds of filters and various coatings
viii. Laminated base fabrics.

4.2. Experimental

4.2.1. Fabric weight measurement

Before testing, the fabric weight was determined. Five pieces of 12 × 12 cm^2 sample were cut from each sample and weighted. The mass per unit area of each fabric was calculated by averaging these five values. Table 4.1 illustrates some characteristics of samples. This experiment was carried out at standard testing atmosphere (20 ± 2 °C and 65±2 % RH).

Table 4.1. Some physical characteristics of samples

	No.	Code No.	Fabric Weight (g/m^2)	Thickness (mm)	Tensile strength N/(5cm)		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	20	0.13	65	20	25	25
	2	CE 2	30	0.17	110	40	25	30
	3	CE 3	40	0.19	150	55	30	30
	4	CE 4	50	0.21	195	75	30	30
	5	CE 5	70	0.25	270	115	30	30
	6	CN 1	20	0.13	65	20	25	25
	7	CN 2	30	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 refers minus pattern, B means point pattern and C represents weave pattern.

E, N and P refer polyester, nylon and polypropylene spun-bond nonwoven respectively

4.2.2. Surface morphology measurement

Before testing, the geometrical characteristics of a material surface was observed by using the SEM (surface scanning electron microscope) in order to get the surface morphology information roughly. The surface morphology of some of the spunbond nonwoven samples is shown in Figure 4.4, Figure 4.5, and Figure 4.6 respectively. Images were taken with 50 X magnification.

4.3. Measuring the Frictional Properties of Spunbond Nonwovens

Nonwoven sample (12 ×12 cm^2) is placed on the horizontal circular sample stage with an iron ring holder and clippers. When the desired load is placed on the sensor head, the sensor wire is brought into contact with the specimen 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 result 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. Measurement was 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 (4.1) and (4.2). 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, $\overline{\mu} = \frac{1}{n}\sum_{i=1}^{n}\mu_i$ ……… (4.1)

Mean deviation, $\mu_A = \frac{1}{n}\sum_{i=1}^{n}|\mu_i - \overline{\mu}|$ ………… (4.2)

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

4.3.1. Dragging angle

In order to know the friction coefficient value against all directions of nonwovens, the dragging angle, θ was defined. The dragging angle, θ is defined 0° when the sensor wire is perpendicular to the 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 4.7 shows the relative positions of sensor wire in different directions of a test.

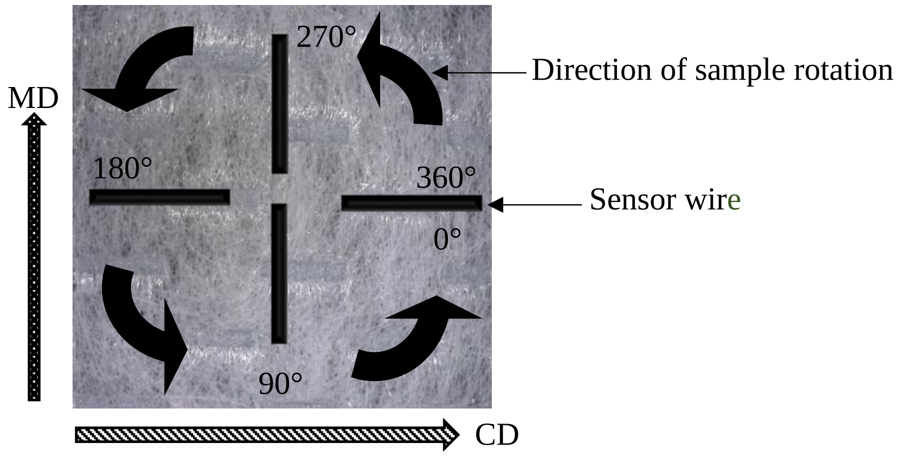


Figure 4.7. The relative positions of sensor wire in different directions of test

4.4. Stick-slip Phenomena (SSP)

Coulomb stated that the static friction force to initiate sliding is greater than the kinetic friction force to maintain sliding. Therefore, the friction trace is intermittent and/or stick-slip phenomenon (SSP) comes out in friction test. In this study, the coefficient of static friction corresponds to the mean friction at sticks and coefficient of kinetic friction corresponds to the mean friction at slips.

Unlike woven, there is no systematic construction in the nonwoven fabric. However, each bonding method has own specific geometric surface. Therefore, the SSP of the coefficient of friction at the micro level that is influenced by the surface morphology and the corresponding mean deviation trace was investigated.

4.4.1. Stick-slip trace of friction coefficient and its mean deviation trace of minus-pattern bonding nonwoven

In minus bonding nonwoven, there is a knob between two adjacent bonding points. The higher the fabric weight, the more the protrusion of knob. As consequence, the regular feature of SSP of the coefficient of friction was found when the sensor wire position is perpendicular to the MD direction of the sample, at 180° of dragging angle. In other words, this is the time when sensor wire travels from one bonding point to the next through knob. When the sensor wire climbs the knob, a resisting force or stick occurs at first and then it hit the peak and it goes down to the next bonding point, resulting in a slip. Therefore, the amplitude of stick and slip is higher at that angle compared to the other dragging angles where the sensor wire seems to pass over the knobs. As a result, the amplitude of stick-slip is low at these angles. Alternatively, a regular feature of SSP was found around at 180° of dragging angle and irregularity of SSP was observed at other dragging degrees. As consequences, the higher value of μ_A was observed at around 180° of dragging angle compared to other angles. This higher value assumed as the peak value. This peak may also appear at 0° and 360° where the sensor wire travels across the unbonding area.

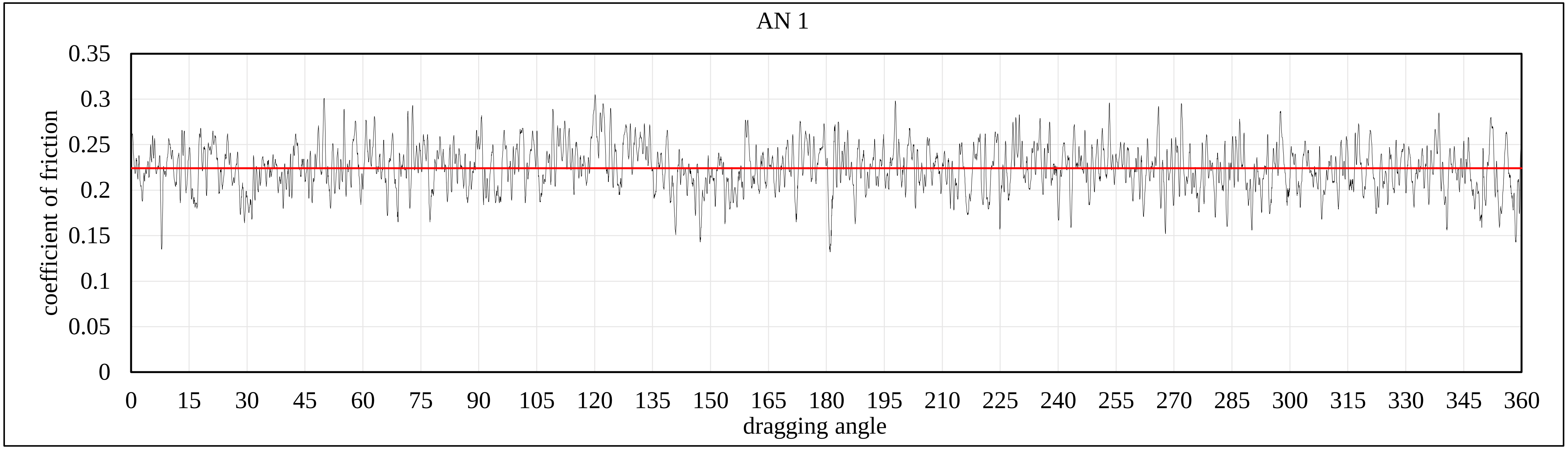
However, this characteristic was not seen clearly in thin and lightweight nonwoven where the protrusion of the knob on the surface was extremely small. Figure 4.8 (a) and (b) show the relation between SSP of friction coefficient and its mean deviation of low weight fabric (AN1) and high weight fabric (AN 4) respectively.

4.4.2. Stick-slip trace of friction coefficient and its mean deviation trace of point-pattern bonding nonwoven

In point-pattern bonding nonwovens, the bonding points are the tiny circular shape and its bonding density is high. Therefore, diagonal lines appear on the surface instead of knobs, especially in the high weight fabrics. As a result, a regular stick slip traces were observed at some degrees, around at 45°, 135°, 225° and 315°, where the sensor wire travels across the diagonal lines. However, there was no clear characteristic in mean deviation trace. In other words, even though there was a high value in mean deviation trace, it did not appear regularly. In low weight fabric, the stick slip trace was irregular through the entire circle and there was no clear characteristic in mean deviation trace. Figure 4.9 (a) and (b) show the relation between SSP of friction coefficient and its mean deviation of low weight fabric (BN1) and high weight fabric (BN 4) respectively.

4.4.3. Stick-slip trace of friction coefficient and its mean deviation trace of weave-pattern bonding nonwoven

Unlike minus and point-pattern bonded nonwovens, the surface geometry of weave-pattern spunbond looks like plain woven fabric. The higher the fabric weight, the clearer the protrusion of unbonding points and these points appear many horizontal and vertical lines on the fabric surface. Therefore, the regularity of stick slip was observed at every 90° of dragging angel where the sensor wire crosses these unbonding points. As a result, the higher value of μ_A appears at every 90° of trace angle regularly. However, the high value in 90° and 270° is slightly lower than that of 180°. This might be the result of changes in direction of dragging from 0°-180° to 180°-360°. This feature also shows up an anisotropic property of spunbond nonwovens. At other angles, the profile is not clear and hence the SSP is irregular. This characteristic is not clear in thin weight fabrics since the protrusion of pattern on the fabric surface is extremely small. Figure 4.10 (a) and (b) show the relation between SSP of friction coefficient and its mean deviation of low weight fabric (CE 1) and high weight fabric (CN 4) respectively.



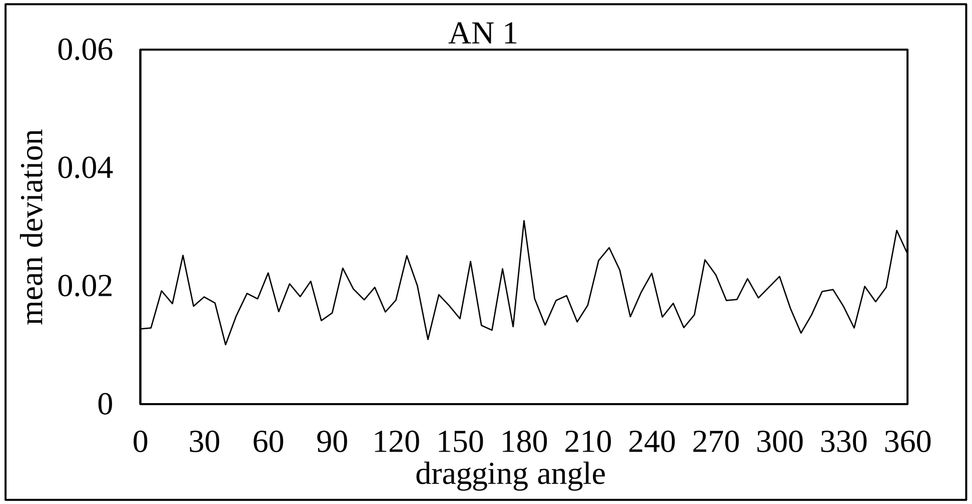
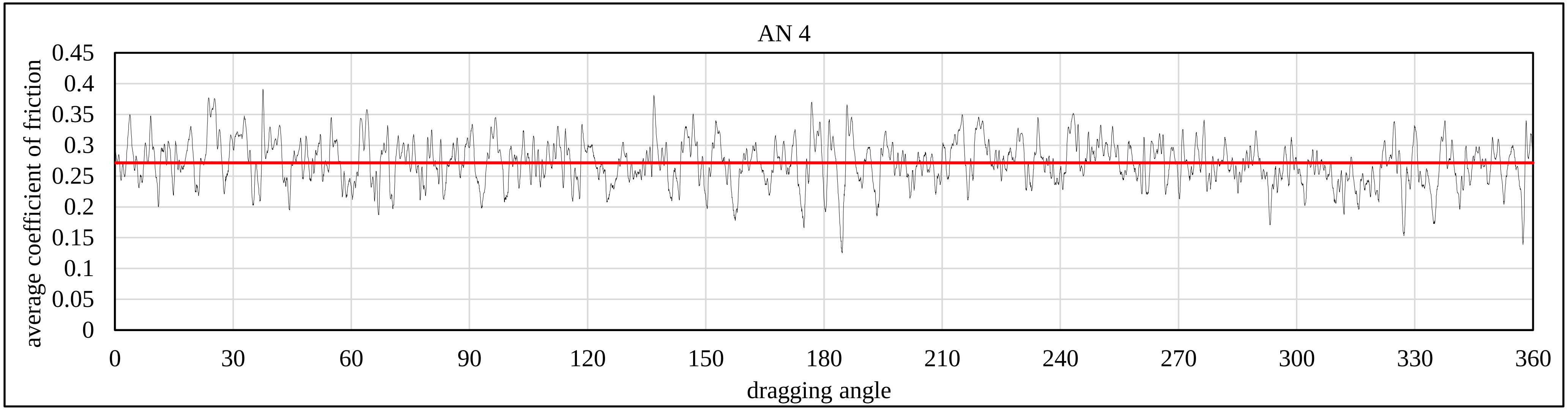


Figure 4.8 (a) The SSP of coefficient of friction and its mean deviation of sample AN 1



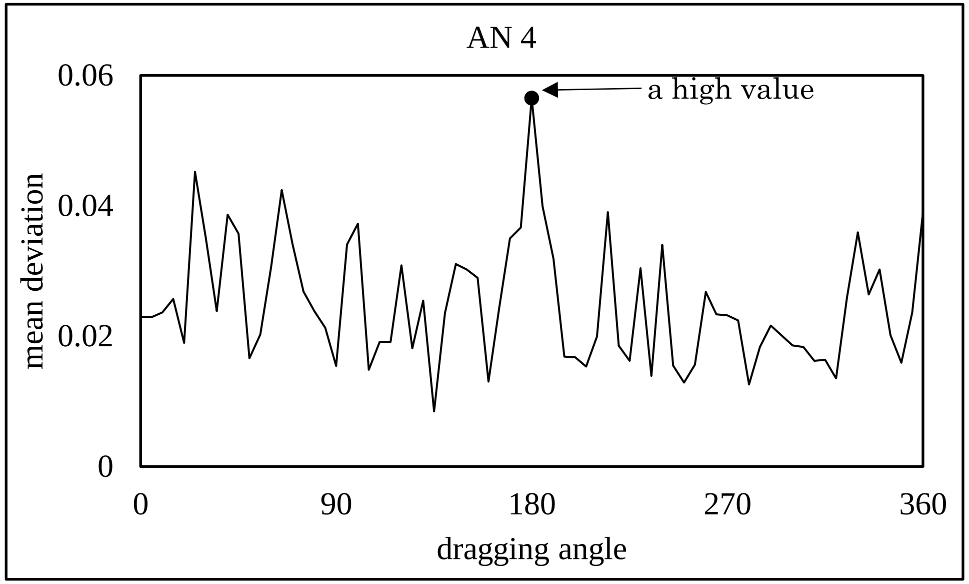
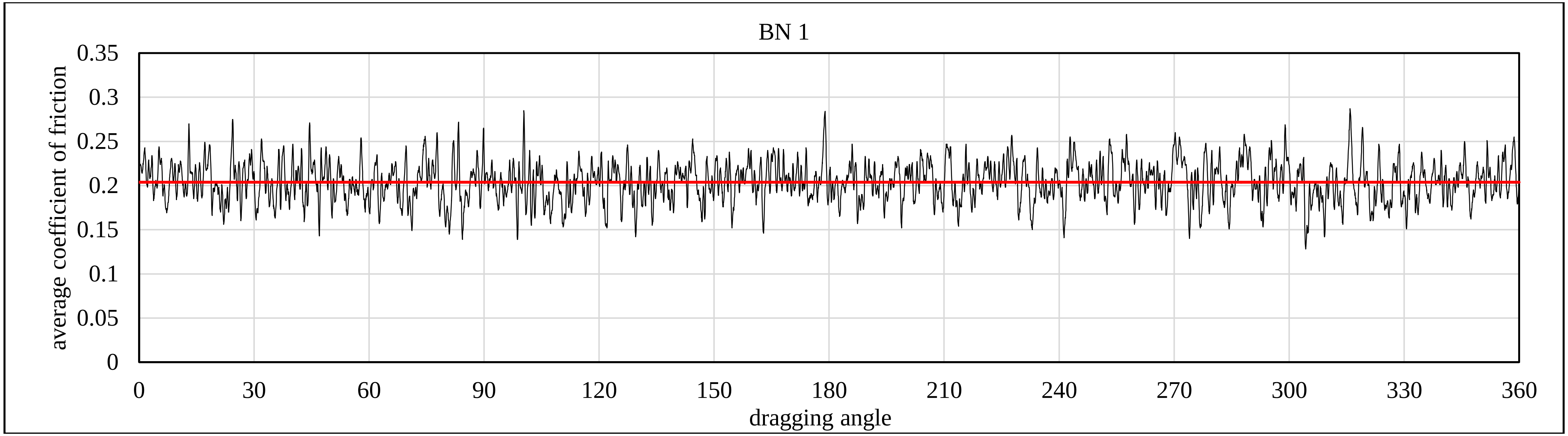


Figure 4.8 (b) The SSP of coefficient of friction and its mean deviation of sample AN 4



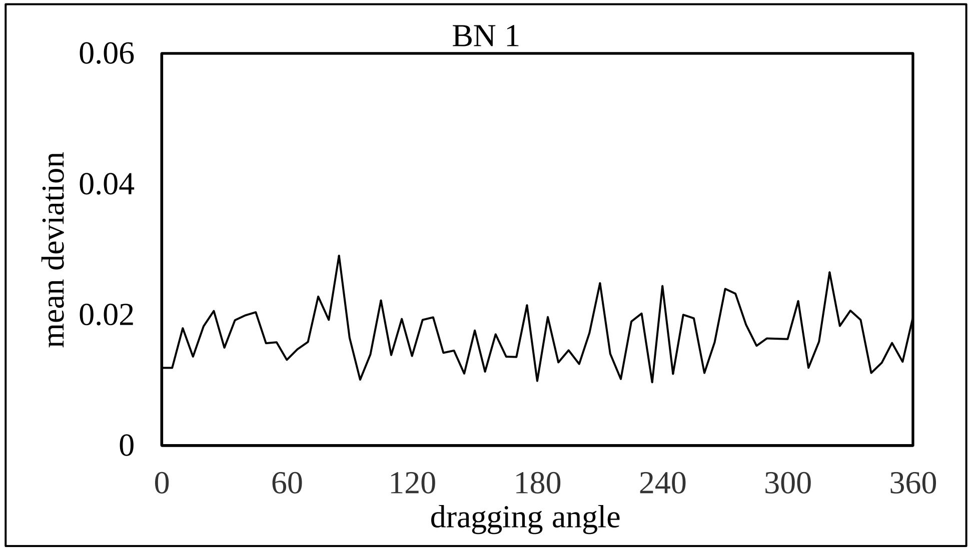
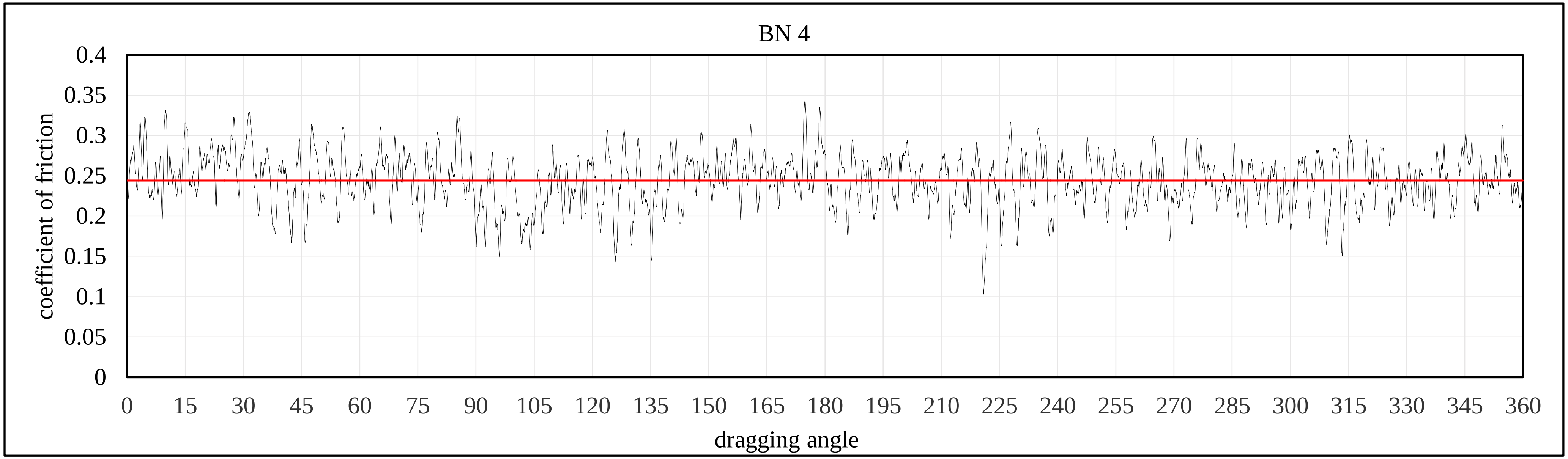


Figure 4.9 (a) The SSP of coefficient of friction and its mean deviation of sample BN 1



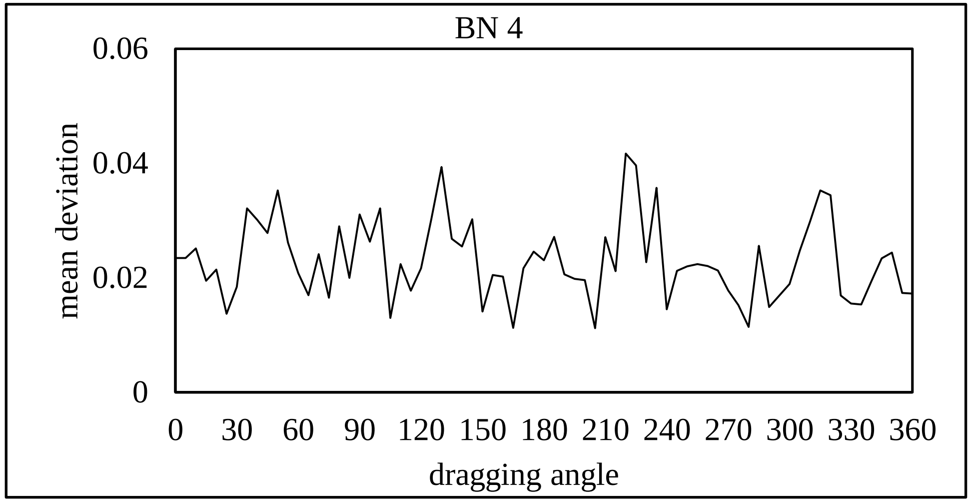


Figure 4.9 (b) The SSP of coefficient of friction and its mean deviation of sample BN 4

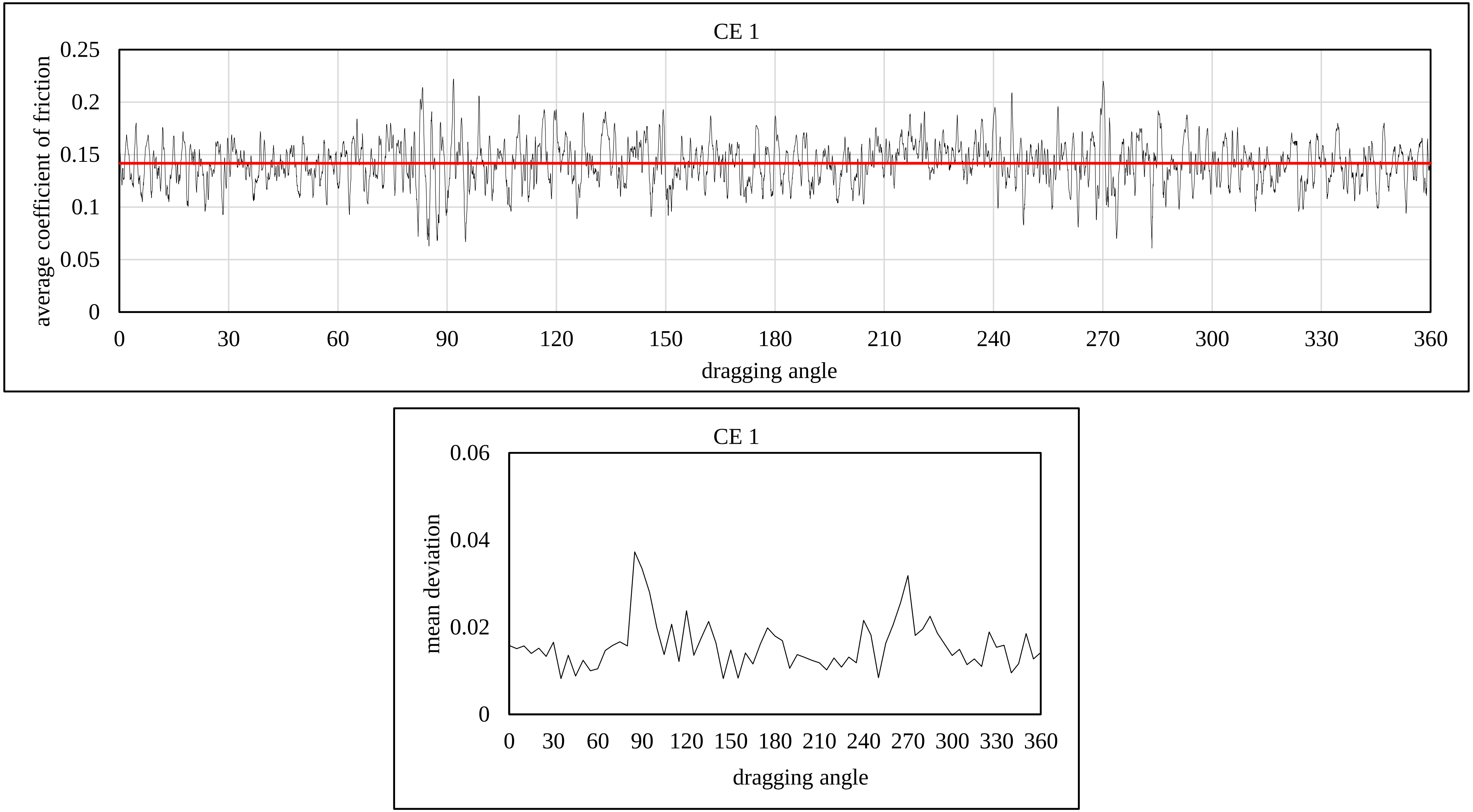
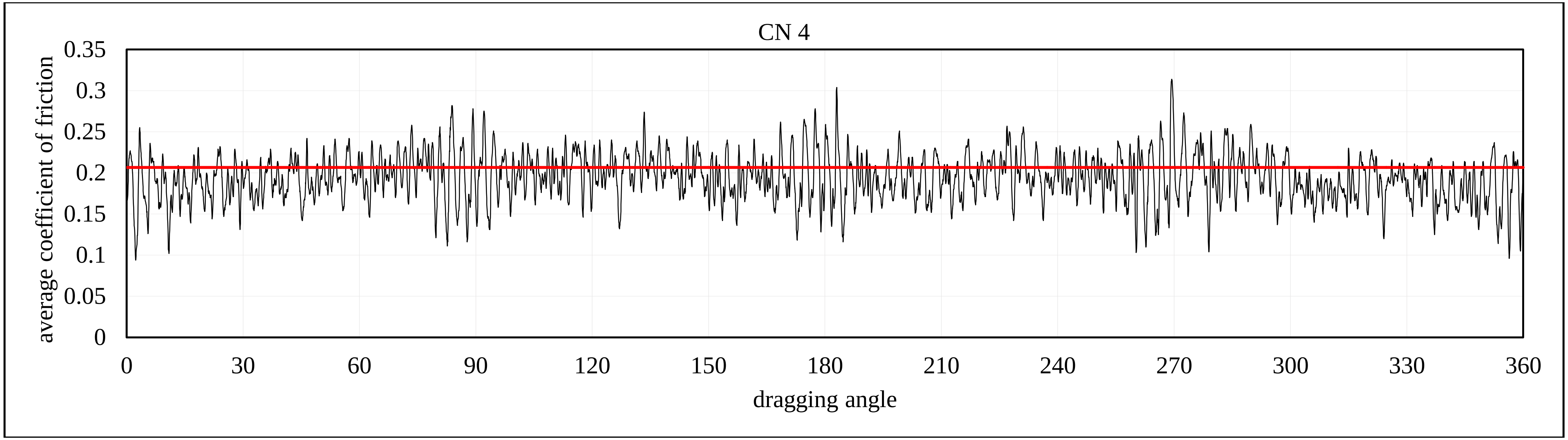


Figure 4.10 (a) The SSP of coefficient of friction and its mean deviation of sample CE 1



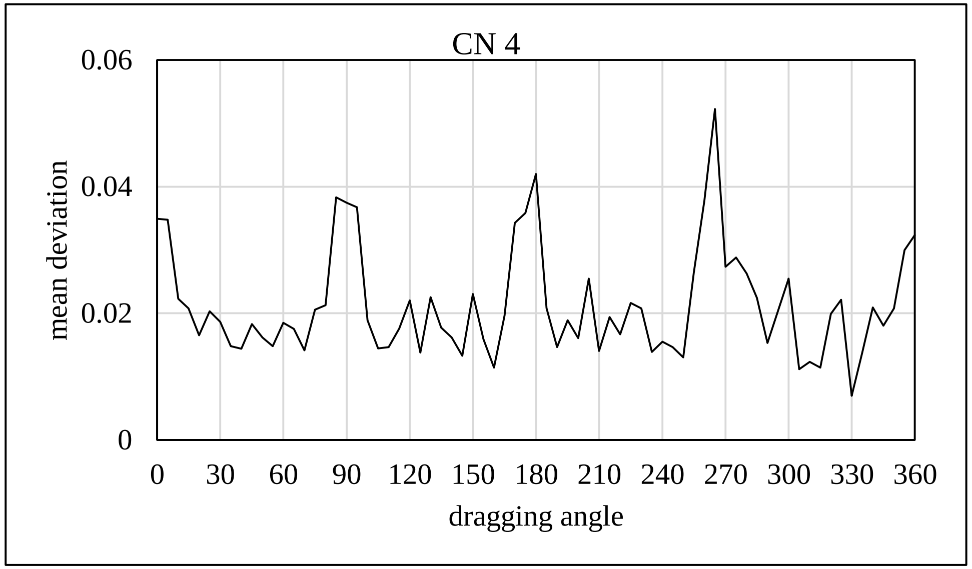


Figure 4.10 (b) The SSP of coefficient of friction and its mean deviation of sample CN 4

4.5. Statistics Analysis of Frictional Properties of Spunbond Nonwoven

ANOVA (Analysis of Variance) method was used in order to know the effect of independent variables, fabric weight, bonding pattern and component filaments on the dependent variable, mean coefficient of friction, μ. α=0.05 was used as a significance level. Therefore, the factor which p-value is less than 0.05 has a significant impact on the mean friction coefficient value.

The resultant values of mean coefficient of friction and mean deviation of all samples are listed in Table A-1, Appendix A. A Shapiro-Wilk's test ($p > 0.05$), shown in Table A-2, Appendix A and Figure 4.11, box-plot result shows that the resultant coefficient of friction values were approximately normally distributed and there were no outliers except some samples. A skewness and kurtosis values, listed in Table A-3, Appendix A showed that the data was between +1.96 SD and -1.96 SD except some samples. However, the data is small (10 data for each sample) to determine the normality and I assumed that the data is approximately normal. The ANOVA result exhibited in Table 4.2 in which model significant p-value less than 0.05 and R-square value 0.95 displays that the model fit to analyze the relationship between dependent variable and independent variables. The result shows that fabric weight, bonding pattern, constituent filament and all interactions except component filament and bonding pattern have the significant impact on friction coefficient.

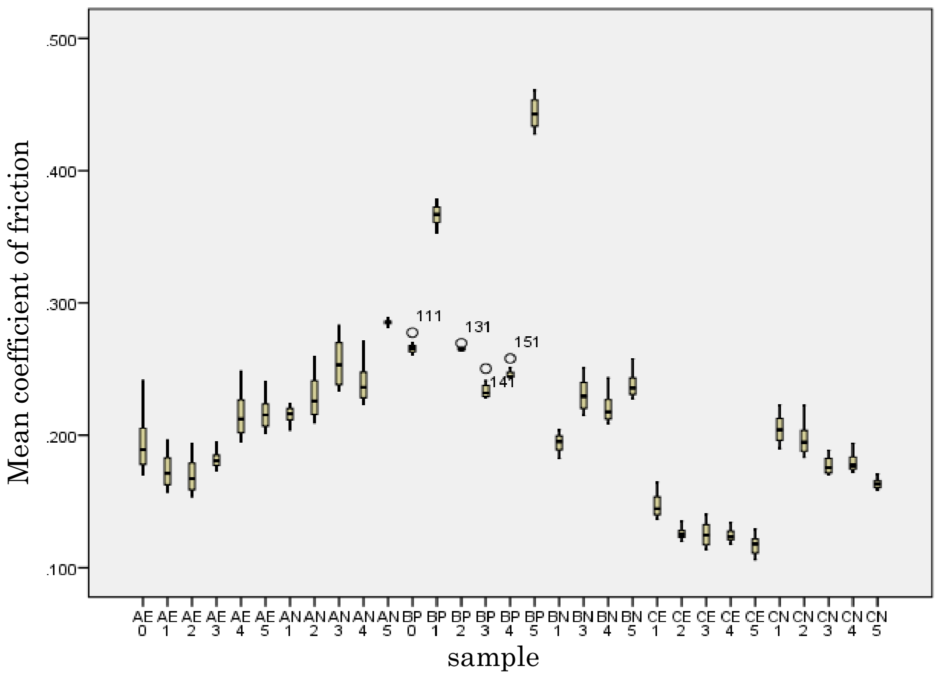


Figure 4.11. Box-plot for spunbond nonwovens

Table 4.2. ANOVA result

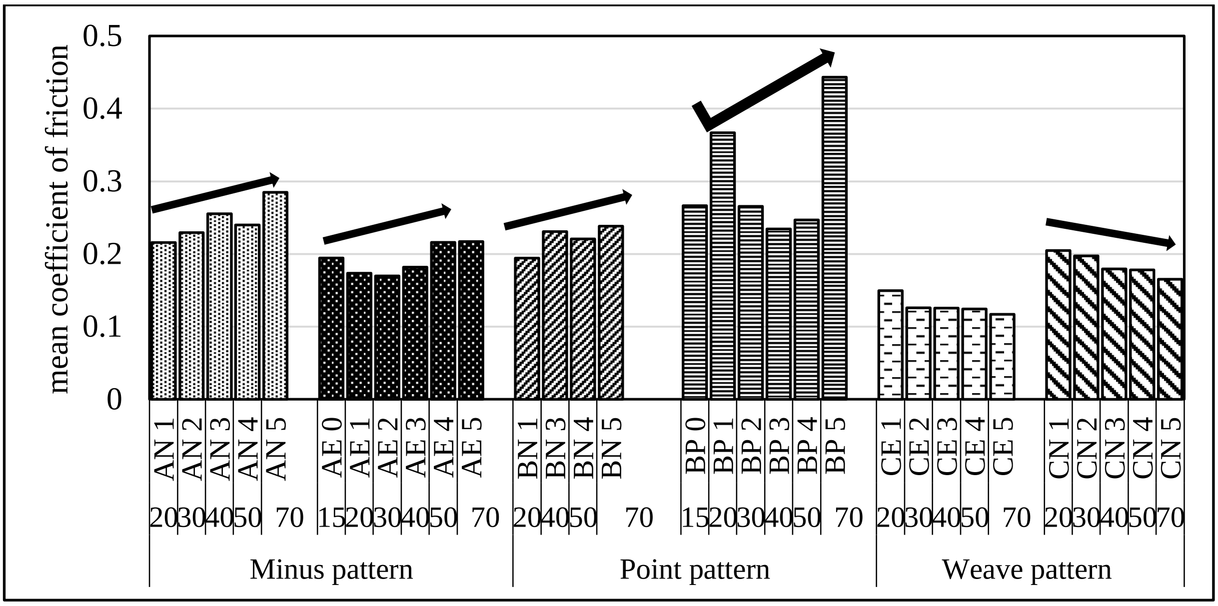
Source	Type III Sum of Squares	df	Mean Square	F	Sig. p-value
Corrected Model	1.398[a]	30	0.047	411.945	0.00
Intercept	13.48	1	13.487	119228.85	0.00
Fabric weight	0.152	5	0.03	269.139	0.00
Pattern	0.194	2	0.097	857.597	0.00
Filament	0.353	2	0.176	1559.009	0.00
Fabric weight * pattern	0.055	7	0.008	69.288	0.00
Fabric weight * filament	0.159	7	0.023	201.272	0.00
Pattern * filament	0.000	1	0.00	1.087	0.298
Fabric weight * pattern * filament	0.006	4	0.001	12.497	0.00
a. R Squared = 0.978 (Adjusted R Squared = 0.976)					

4.6. Factors Affecting on Mean Coefficient of Friction

After performing an ANOVA, the multiple comparison analysis (MCA) test or post hoc test was conducted in order to get the detailed information of differences within groups. Scheffe test was used to find out all possible contrasts which are significant. Since the factors affecting on 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 with possible influencing factors are discussed together.

4.6.1. Effect of fabric mass per unit area

Figure 4.12 shows the resultant values of mean coefficient of friction of minus-pattern, point-pattern and weave-pattern bonding spunbond fabrics. Generally, it can be seen that mean friction coefficient value increased when the fabric weight increased in nylon and polyester minus-pattern bonding spunbond nonwovens. The reason is that the impact of not only the fabric density but also the surface architecture that varies with the bonding method. Generally, the fabric surface is uneven in low weight and a more even surface can achieve with increasing mass per unit area. On the other hand, an even surface develops only from one bonding point to the next when the fabric density increase. Therefore, the unbounded area between two-bounded areas appears as a knob on the fabric surface that create an additional resistance during dragging. Hence, the coefficient of friction increase again. The multiple comparison results shown in Table 4.3 (a), and (b) confirm this tendency.



**15,20,30,50,70 refer fabric mass per unit area*

Figure 4.12. Changes in coefficient of friction for different fabric weight

According to the multiple comparison analysis test results, shown in Table 4.3 (c) and (d), the mean coefficient of friction value is high when the fabric weight increase in the nylon point-pattern spunbond. In the polypropylene point-pattern spunbond nonwoven, the coefficient of friction value increased at first, and then it hit the lowest value at a certain weight and beyond this point, it increased again. Generally, the surface is uneven in low weight fabric and hence the value of friction coefficient increases. At a certain fabric weight per unit area that gives an even surface so that the value of friction coefficient is the lowest. Beyond this point, as the fabric density increases, the thickness of fabric increases and the depth of bonding points is large accordingly. The surface smoothness is not as much as before and hence the value of friction coefficient is high again.

On the contrary, the bonding density of weave-pattern bonding nonwoven is higher than that of minus-pattern and point-pattern bonding nonwovens. Hence, a thin and paper-like surface appears with an increase in fabric weight. In other words, an even surface appears when the fabric weight increase. Therefore, the value of the coefficient of friction decreased with the higher fabric density in nylon weave-pattern spunbond fabrics. However, there is no difference within polyester weave-pattern spunbond fabrics. Because these fabrics look like paper. The resultant multiple comparisons are illustrated in Table 4.3 (e) and (f).

Table 4.3. Multiple comparison results of friction coefficient for different fabric weight

	AE 0	AE 1	AE 2	AE 3	AE 4	AE 5
AE 0						
AE 1	–					
AE 2	–	–				
AE 3	–	–	–			
AE 4	–	*	*	*		
AE 5	–	*	*	*	–	

(a)

	AN 1	AN 2	AN 3	AN 4	AN 5
AN 1					
AN 2	–				
AN 3	*	–			
AN 4	–	–	–		
AN 5	*	*	*	*	

(b)

	BP 0	BP 1	BP 2	BP 3	BP 4	BP 5
BP 0						
BP 1	*					
BP 2	–	*				
BP 3	*	*	–			
BP 4	–	*	–	–		
BP 5	*	*	*	*	*	

(c)

	BN 1	BN 3	BN 4	BN 5
BN 1				
BN 3	*			
BN 4	–	–		
BN 5	*	–	–	

(d)

	CN 1	CN 2	CN 3	CN 4	CN 5
CN 1					
CN 2	–				
CN 3	–	–			
CN 4	–	–	–		
CN 5	*	*	–	–	

(e)

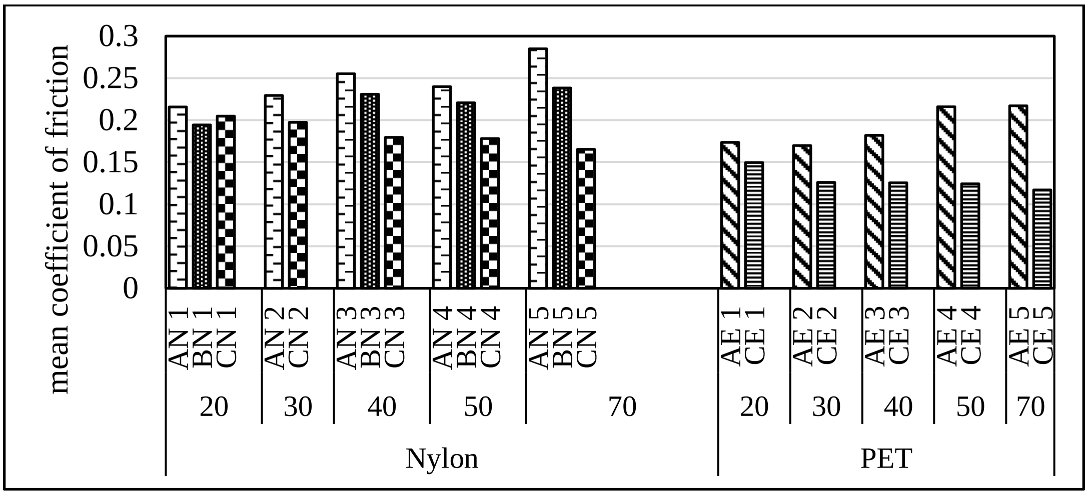
	AN 1	AN 2	AN 3	AN 4	AN 5
AN 1					
AN 2	–				
AN 3	*	–			
AN 4	–	–	–		
AN 5	*	*	*	*	

(f)

* *represents the corresponding pairs are significantly different at 0.05 level*

4.6.2. Effect of bonding pattern

Figure 4.13 illustrates the effect of bonding pattern on the value of mean friction coefficient value and Table 4.4 (a), (b), and (c) show the multiple comparison analysis results. According to the experimental result, the mean coefficient of friction value of minus-pattern bonding spunbond is higher than that of weave-pattern spunbond nonwoven. Point-pattern bonding spunbond has a higher coefficient of friction value compared to weave-pattern bonding spunbond. There is no significant difference between minus-pattern and point-pattern bonding spunbond. However, there was no significant difference among three patterns in low weight fabrics, especially for nylon spunbond nonwovens. This might be the cause of orientation of filaments throughout the surface is not balance in low weight fabrics and the effect of bonding pattern is not much since the protrusion of unbonding area is extremely small.



**15,20,30,50,70 refer fabric mass per unit area*

**A,B,C refer minus, point and weave bonding pattern respectively*

Figure 4.13. Changes in coefficient of friction for different bonding pattern

When the fabric weight increases, the protrusion of unbounded point in the minus-pattern bonding nonwoven is the highest because of 15% of the total surface area is bonded. Therefore, the protrusions of unbounded points create an additional friction resistance. In the point-pattern bonding nonwoven, the bonding density is high with the bonding area of 11% so that the filaments that expose to the air resist when the sensor wire drags over them. Because of higher bonding density in weave-pattern bonding nonwoven, it seems only the pattern protrusion causes the frictional resistance hence the mean coefficient of friction is the lowest.

Table 4.4. Multiple comparison results of friction coefficient for different bonding pattern

	AN1	BN1	CN1		AN2	BN2		AN3	BN3	CN3
AN1				AN2			AN3			
BN1	-			BN2	-		BN3	-		
CN1	-	-					CN3	-	-	

(a)

	AN4	BN4	CN4		AN5	BN5	CN5
AN4				AN5			
BN4	-			BN5	-		
CN4	*	*		CN5	*	*	

(b)

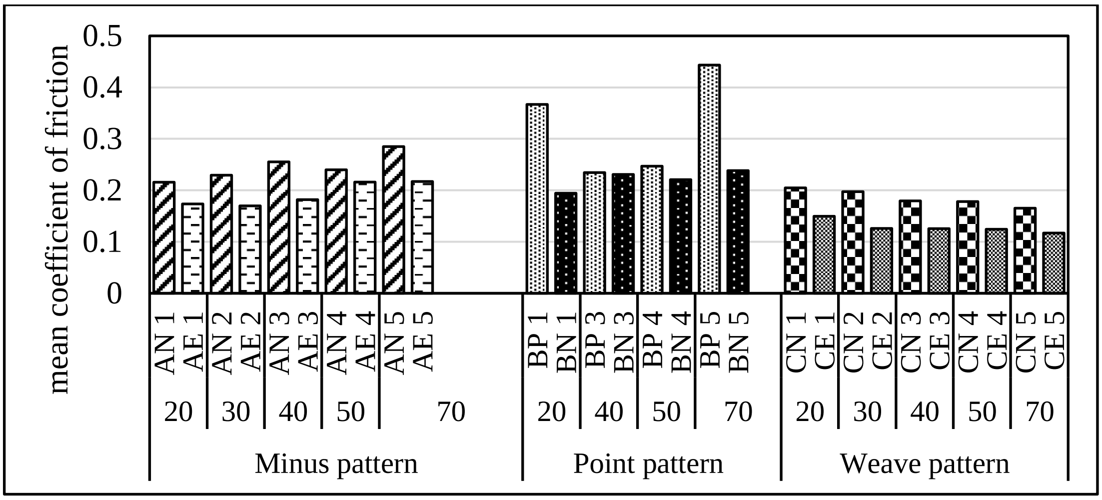
	AE1	CE1		AE2	CE2		AE3	CE3		AE4	CE4		AE5	CE5
AE1			AE2			AE3			AE4			AE5		
CE1	*		CE2	*		CE3	*		CE4	*		CE5	*	

(c)

* *represents the corresponding pairs are significantly different at 0.05 level*

4.6.3. Effect of component filaments

In the case of same bonded pattern and fabric density, it is observed that the value of friction coefficient of polypropylene nonwoven is higher than that of nylon spunbond and nylon spunbond has a higher mean coefficient of friction value than polyester spunbond. This result is illustrated in Figure 4.14 and the multiple comparison results are shown in Table 4.5(a), (b), and (c). It is difficult to interpret that not only the filament properties, for instance, diameter, and but also the producing parameters such as bonding temperature and time have an influence on it.



**15,20,30,50,70 refer fabric mass per unit area*

**A,B,C refer minus, point and weave bonding pattern respectively*

Figure 4.14. Changes in coefficient of friction for different component filament

Table 4.5. Multiple comparison results of friction coefficient for different component filaments

	AN1	AE1		AN2	AE2		AN3	AE3		AN4	AE4		AN5	AE5
AN1			AN2			AN3			AN4			AN5		
AE1	-		AE2	-		AE3	-		AE4	*		AE5	-	

(a)

	BP1	BN1		BP3	BN3		BP4	BN4		BP5	BN5
BP1			BP3			BP4			BP5		
BN1	*		BN3	*		BN4	-		BN5	-	

(b)

	CN1	CE1		CN2	CE2		CN3	CE3		CN4	CE4		CN5	CE5
CN1			CN2			CN3			CN4			CN5		
CE1	*		CE2	*		CE3	*		CE4	*		CE5	*	

* *represents the corresponding pairs are significantly different at 0.05 level*

(c)

4.7. Summary

In this work, the frictional behavior of spunbond nonwoven fabrics was studied. By using a simple whisker type tactile sensing machine, the frictional characteristics in all directions of spunbond nonwoven can be measured. Based on the experimental results, it is concluded as follows:

1. The specific geometric surface of each bonding pattern influence on the resultant SSP trace and hence mean deviation trace.
2. The bonding method, material itself and fabric density have a great impact on the mean coefficient of friction. Moreover, except the interaction between the filament and pattern, the other interactions influenced on the coefficient of friction value.
3. In the case of same fabric density and constituent filaments, the value of friction coefficient of minus pattern bonding spunbond and point-pattern bonding spunbond is higher than that of weave-pattern bonding spunbond. However, there is no significant difference between minus and point-pattern bonding spunbond nonwoven.
4. The value of friction coefficient of polypropylene nonwoven is larger than that of nylon spunbond in the case of same bonding pattern and fabric density. The nylon spunbond nonwoven has a large coefficient of friction value vcompared to polyester spunbond nonwoven.
5. When the component filament and bonding pattern are constant, the coefficient of friction value generally increased when the fabric density increased in minus and point-pattern bonding nonwoven. The reason is the effect of protrusion of unbonding points on the fabric surface which creates an additional resistance during dragging. In weave-pattern bonding nonwoven, the value of the coefficient

of friction decreased when the fabric density increased because an even surface achieves in high fabric density with higher bonding density.

Overall, it is clear that simple whisker type friction testing machine has a capability of assessing the coefficient of friction value in all directions and it can also interpret the influencing factors of friction coefficient value.

CHAPTER 5
THE COMPARATIVE STUDY OF KAWABATA (KES-FB) AND SIMPLE WHISKER FRICTION TESTING MACHINE

Because friction is not an inherent property and it changes with the testing conditions such as normal load and dragging speed and material itself. Therefore, there still have been a limitation in using a new method. This chapter deals with the comparative study of the standard test method, Kawabata Evaluation System (KES) and rotational dragging method in order to know the capability of rotational dragging method in detecting the coefficient of friction.

In the first part of this chapter, the working principle and evaluation method of Kawabata surface tester was described. The second part of the chapter concerns with the comparison between KES and rotational dragging method to access the capability of rotational dragging method.

5.1. Kawabata Evaluation System

Professor Emeritus Sueo Kawabata (Kyoto University, Japan) and his co-founder Niwa has developed an objectively unique measurement method of assessing fabric hand for taking place of assessment of fabrics by skillful person subjectively. In this method, four instruments, tensile and shearing testing machine, pure bending testing machine, compressional testing machine, and surface testing machine, are used to determine the mechanical properties of the fabric from which total hand value of the sample is calculated. Moreover, the hysteresis effect in the mechanical deformation process can also be characterized. In this study, the surface tester was used to evaluated friction of the spunbond nonwoven fabrics.

Surface friction and roughness tester (KES-FB 4) can measure the friction of the fabric surface. The sample size is not specified but the sample of 2 cm long and 0.5 cm wide must be measured effectively. Ten pieces of 0.5 mm diameter steel piano wire are piled up and used as friction detector, which resembles the sense of the human finger. 50gf dead weight is used for compression. Figure 5.1 shows the detector for surface friction test [13].

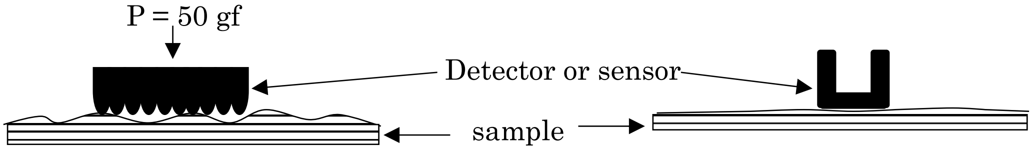


Figure 5.1. Detector for surface friction test

The speed of the specimen is 1 mm/sec and 20 gf/cm tension exerted on it. Friction property is defined by two surface characteristic values, namely, MIU and MMD for both warp (MD) and weft (CD) directions of the specimen. The average value of μ in a distance of 20 mm is denoted as MIU. MMD is the degree of variation that determines how much of a change from MIU is present. Both MMD and MIU have no unit. Figure 5.2 (a) and (b) illustrate the corresponding graph of surface friction, MIU, and MMD. Equation 5.1 and 5.2 show the formula of MIU and MMD respectively [13]. The higher the value of MIU, the lesser the tendency to slip. A higher value of MMD means less smoothness and more roughness.

Mean value of the coefficient of friction, $MIU = \frac{1}{X}\int_0^X \mu\, \delta x$ ………..(5.1)

Mean deviation of coefficient of friction, $MMD = \frac{1}{X}\int_0^X |\mu - \overline{\mu}|\, \delta x$ …..….(5.2)

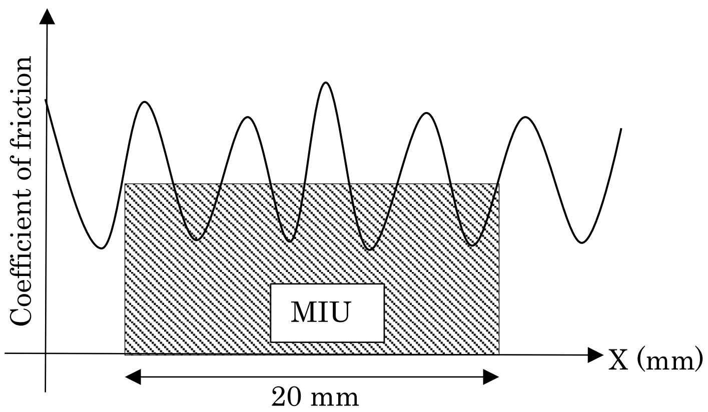
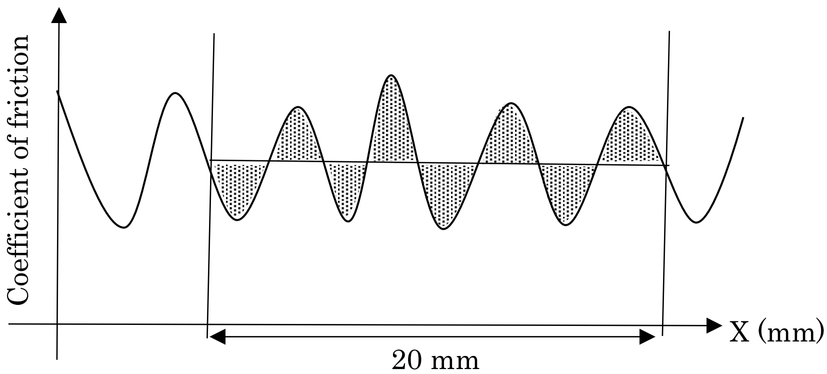


Figure 5.2 (a) Surface friction (MIU)



5.2 (b) Surface friction (MMD = hatched area/ X)

5.2. Experimental Method

5.2.1. Sample

To find out the distinctions between KES and rotational dragging friction testing machine, the MIU and mean coefficient of friction value of spunbond nonwoven fabrics were measured with both methods. The samples are composed of polyester (PET), polypropylene (PP) and nylon with the weight vary from 15 g/m^2 to 70 g/m^2. They are bonded by three patterns, minus-pattern, point-pattern and weave-pattern. Some physical properties of these samples are shown in Table 4.1. Chapter 4.

5.2.2. Friction test with surface tester (KES-FB 4)

20 × 20 cm^2 sample was cut and placed on the machine with the exerted tension of 20 gf/cm. The dead weight 50g was used for compressive force. The speed of specimen is 1 mm/s. The coefficient of friction (MIU) value of nonwoven surface, 2 cm in length, in both MD and CD were recorded. Ten different places of the face side of each specimen were measured and calculated the average value. The experiment was carried out at standard testing atmosphere (20 ± 2°C and 65 ± 2 % RH). The resultant values of MIU are listed in Table B-1, Appendix B. Figure 5.3 shows the KES-FB 4 tester in testing condition.

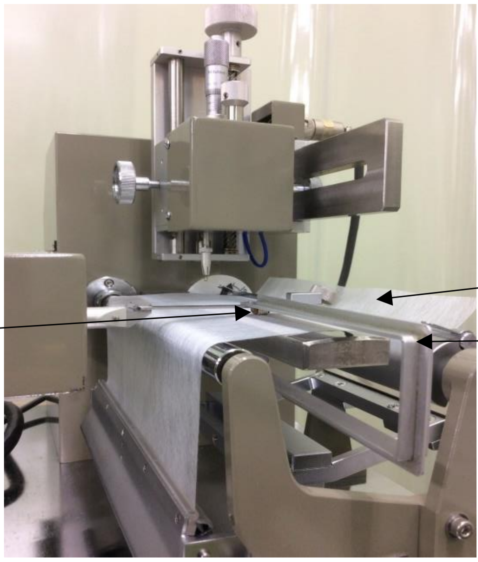


Figure 5.3 Surface friction and roughness tester (KES-FB 4)

5.2.3. Friction test with rotational dragging machine

12 cm^2 sample was placed on the sample stage with an iron ring and clippers. After placing the 30g load on the load cell, the sample stage was keep in motion from 0° to 360°. Therefore, the friction force comes out between the fabric surface and sensor wire. This friction force and the normal force were recorded and the coefficient of friction was calculated by taking the ratio of friction force and normal force. The sample stage speed is 0.5 rpm and the turning radius of sensor wire is 20mm. Therefore, the speed of the sensor wire is 1 mm/s. 10 readings were taken for each sample and the mean coefficient of friction value

was calculated by using equation 5.1. The experiment was carried out at standard testing atmosphere (20 ± 2°C and 65 ± 2 % RH). The resultant mean coefficient of friction values of all samples are listed in Table A-1, Appendix A.

Mean coefficient of friction, $\overline{\mu} = \frac{1}{n}\sum_{i=1}^{n}\mu_i$ ……… (5.1)

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

5.3. Statistics Analysis of MIU

Before accessing the capability of a rotational dragging method, the influencing factors on MIU value was determined by using SPSS statistical software. ANOVA (Analysis of Variance) method was used in order to know the effect of independent variables, fabric weight, bonding pattern and component filaments on the dependent variable, MIU value. α=0.05 was used as a significance level. Therefore, the factor which p-value is less than 0.05 has a significant impact on the mean friction coefficient value (MIU).

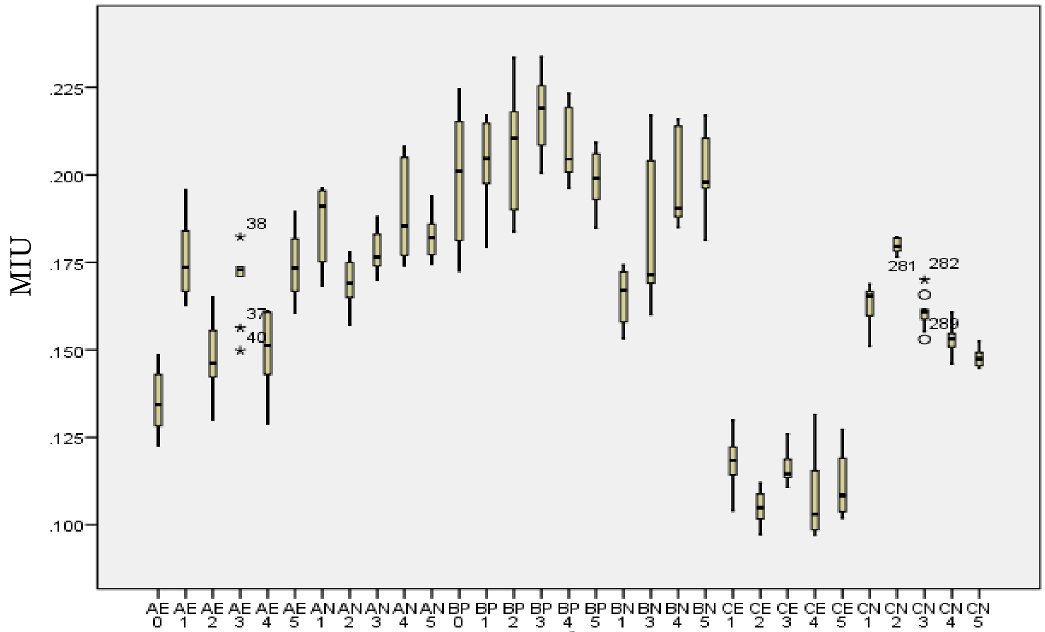


Figure 5.4. MIU value of Spunbond nonwoven samples

A Shapiro-Wilk's test ($p > 0.05$), shown in Table B-2, Appendix B and Figure 5.4, the box-plot result shows that the MIU values of all samples were approximately normally distributed and there were no outliers except some samples. A skewness and kurtosis values, listed in Table B-3, Appendix B showed that the data was between +1.96 SD and -1.96 SD except some samples. However, the data is small (10 data for each sample) to determine the normality and I assumed that the data is approximately normal. The ANOVA result exhibited in Table 5.1 in which model significant p-value less than 0.05 and R-square value 0.95 display that the model fit to analyze the relationship between dependent variable and independent variables. The result shows that fabric weight, bonding pattern, constituent filament and all interactions have the significant impact on friction coefficient.

Table 5.1. ANOVA result of MIU

Source	Type III Sum of Squares	df	Mean Square	F	Sig. (p – value)
Corrected Model	0.309[a]	30	0.01	94.249	0.00
Intercept	8.001	1	8.001	73237.4	0.00
Fabric weight	0.007	5	0.001	12.52	0.00
Component filament	0.064	2	0.032	293.55	0.00
Bonding pattern	0.071	2	0.036	326.32	0.00
Fabric weight * component filament	0.011	7	0.002	14.56	0.00
Fabric weight * bonding pattern	0.014	7	0.002	17.83	0.00
Component filament *bonding pattern	0.013	1	0.013	118.97	0.00
Fabric weight * component filament * bonding pattern	0.003	4	0.001	7.05	0.00
a. R Squared = 0.91 (Adjusted R Squared = 0.9)					

5.4. Correlation between MIU and Mean Coefficient of Friction, μ

The factors affecting on the mean coefficient of friction are generally the same for both methods, KES and rotational dragging method. Therefore, the correlation between these two methods was carried out. Figure 5.5 shows the MIU values and mean coefficient of friction values for all samples. It can be seen that the coefficient of friction value is higher than the MIU value for all fabrics. Figure 5.6 illustrates the correlation value of two methods. It is observed that there is a strong correlation for weave-pattern bonding spunbond nonwoven with the value of 0.95 whereas there is a weak correlation for minus-pattern and point-pattern bonding spunbond with the value of 0.51 and 0.25 respectively.

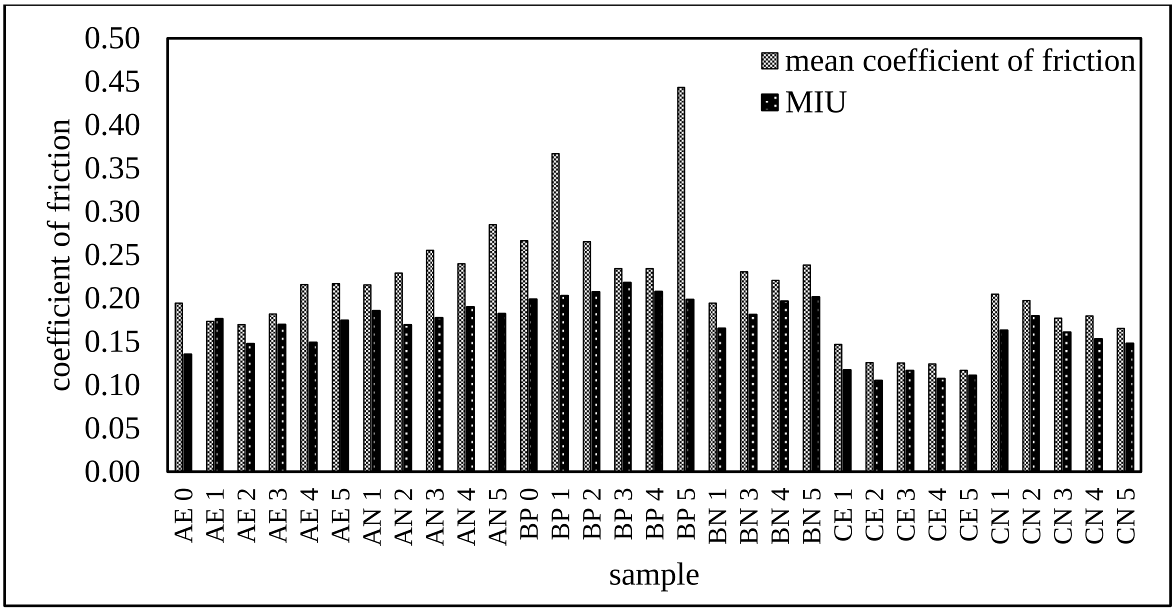


Figure 5.5. MIU and mean coefficient of friction value for all samples

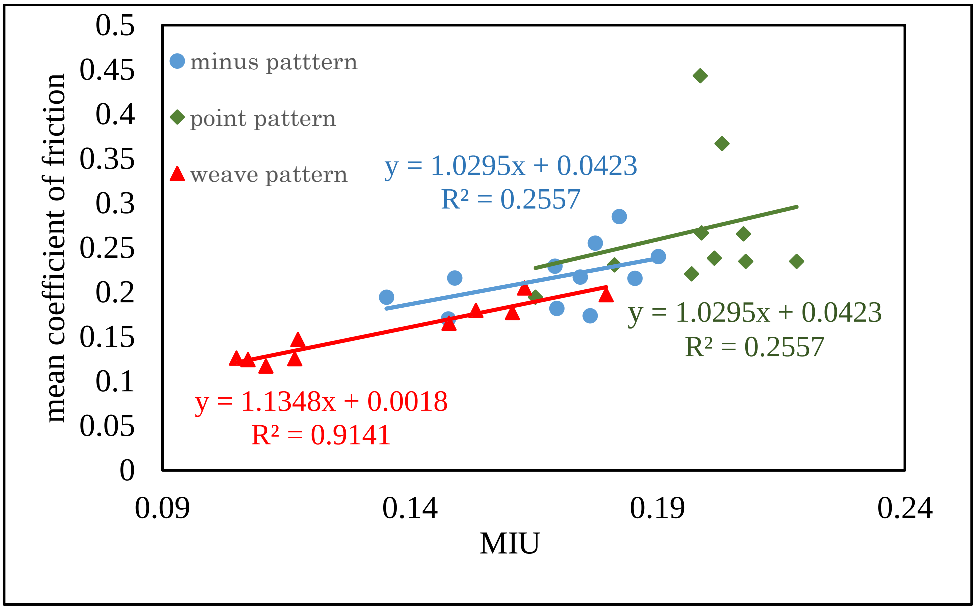


Figure 5.6. Correlation between MIU and mean coefficient of friction

The reason might be an impact of bonding pattern. In weave-pattern spunbond, the surface geometry of both MD and CD are the same. Even though the surface geometry is the same in both MD and CD, the resultant surface is lofty because of small diameter bonding points in point-pattern spunbond. Therefore, it seems that the KES detector travels over the surface while whisker sensor trusts into the surface and drags over it. In minus-pattern spunbond, because of different surface geometry in MD and CD, KES sensor seems to travel over the unbonding point and fails to detect the bonding point in both directions, however, whisker sensor travels from one bonding point to the next especially when the sensor wire is perpendicular to the MD of the sample.

Since the coefficient of friction property is influenced by multivariable, the coefficient of determination value was calculated from the regression line to show percentage variation in mean coefficient of friction value against the MIU value. R^2 value for weave-pattern, point-pattern and minus-pattern bonding are 91 %, 26% and 26% respectively.

5.5. Comparative Result of MIU and Mean Coefficient of Friction, μ

5.5.1. Capability of assessing the influence of fabric weight on coefficient of friction

In order to test the capability of assessing the influence of fabric weight on the friction properties, spunbond nonwoven fabrics with the weight vary from 15 g/m^2 to 70g/m^2 were tested with both methods. Then, the results were analyzed with SPSS statistical package. Table 5.2 (a), (b), (c), (d), (e) and (f) show the multiple comparison analysis results (Scheffee test result) of MIU values of all samples from which the tendency of mean coefficient of friction affected by the fabric density was determined. Figure 5.7 shows the tendency of the effect of fabric density on the MIU values.

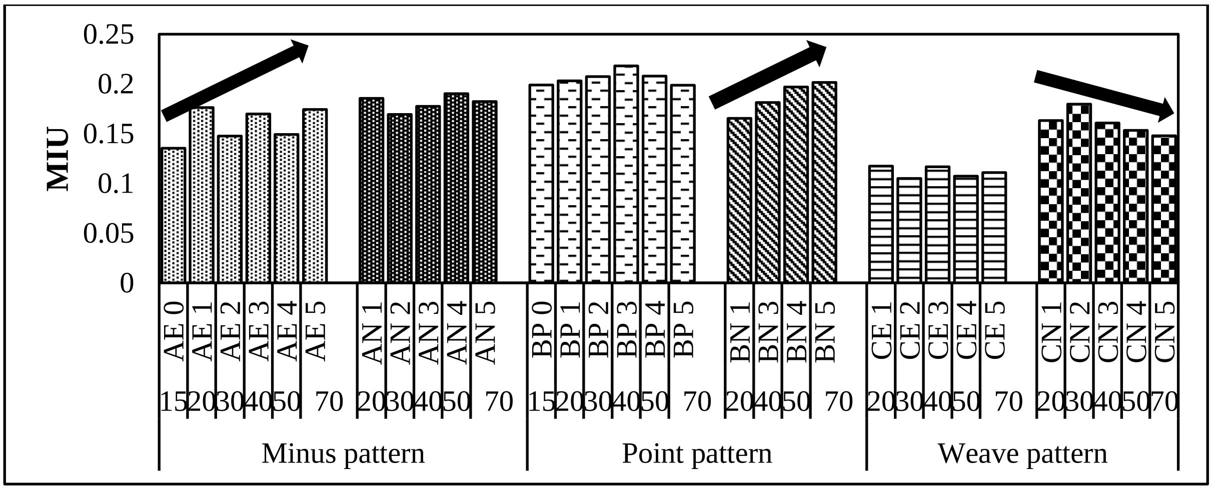


Figure 5.7. Effect of fabric density on MIU values

According to the statistical analysis result, the tendencies of MIU and $\overline{\mu}$ are the same for polyester minus-pattern spunbonds. However, there is no difference or tendency within the group of MIU of nylon minus-pattern spunbond nonwovens.

In nylon point-pattern spunbond nonwovens, the resultant tendencies of MIU and mean coefficient of friction are equal whereas there is no tendency of MIU for polypropylene point-pattern spunbond nonwovens.

There were no tendencies for MIU and mean coefficient of friction for polyester weave-pattern spunbond nonwovens. The tendency of MIU is as same as that of mean coefficient of friction in nylon weave-pattern spunbond nonwoven fabrics.

Table 5.2. The Scheffee test result of MIU for different fabric weight

	AE 0	AE 1	AE 2	AE 3	AE 4	AE 5
AE 0						
AE 1	*					
AE 2	-	-				
AE 3	*	-	-			
AE 4	-	-	-	-		
AE 5	*	-	-	-	-	

(a)

	AN 1	AN 2	AN 3	AN 4	AN 5
AN 1					
AN 2	-				
AN 3	-	-			
AN 4	-	-	-		
AN 5	-	-	-	-	

(b)

	BP 0	BP 1	BP 2	BP 3	BP 4	BP 5
BP 0						
BP 1	-					
BP 2	-	-				
BP 3	-	-	-			
BP 4	-	-	-	-		
BP 5	-	-	-	-	-	

(c)

	BN 1	BN 3	BN 4	BN 5
BN 1				
BN 3	-			
BN 4	*	-		
BN 5	*	-	-	

(d)

	CN 1	CN 2	CN 3	CN 4	CN 5
CN 1					
CN 2	-				
CN 3	-	-			
CN 4	-	-	-		
CN 5	-	*	-	-	

(e)

	CE 1	CE 2	CE 3	CE 4	CE 5
CE 1					
CE 2	-				
CE 3	-	-			
CE 4	-	-	-		
CE 5	-	-	-	-	

(f)

*. *The mean difference is significant at 0.05 level.*

According to the multiple comparison results within each group for both methods, the number of pairwise difference within each group for rotational dragging method is higher than that of KES. For the PET minus-pattern spunbond nonwovens, 4 pairwise differences in rotatory method and 3 pairwise differences in MIU. There are 6 pairwise differences in rotatory for nylon minus-pattern spunbond nonwoven whereas there is no pairwise difference in MIU. The number of pairwise differences, 2 pairwise differences, is the same for both methods in nylon point-pattern spunbond nonwoven fabrics. Even though there is no pairwise difference in PP point-pattern spunbond nonwoven fabrics, 10 number of pairwise differences were observed in rotatory method. There is no pairwise difference for both methods in PET weave-pattern spunbond nonwovens. There are two pairwise differences was observed for rotatory whereas only one pair was observed in MIU for nylon weave-pattern spunbond nonwovens. Therefore, it is concluded that rotational dragging method is more sensitive in detecting the effect of fabric density on the friction property.

5.5.2. Capability of assessing the influence of bonding method

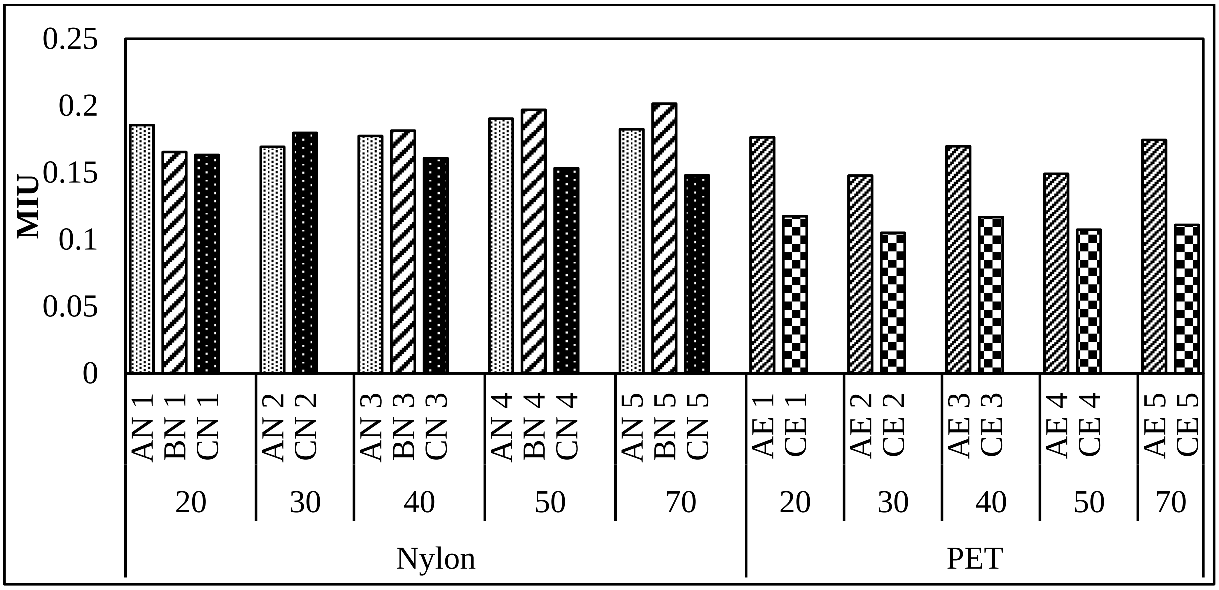


Figure 5.8. Effect of bonding pattern on MIU values

Table 5.3. The Scheffee test result of MIU for different bonding pattern

	AN1	BN1	CN1		AN2	BN2		AN3	BN3	CN3
AN1				AN2			AN3			
BN1	-			BN2	-		BN3	-		
CN1	-	-					CN3	-	-	

(a)

	AN4	BN4	CN4		AN5	BN5	CN5
AN4				AN5			
BN4	-			BN5	-		
CN4	*	*		CN5	*	*	

(b)

	AE1	CE1		AE2	CE2		AE3	CE3		AE4	CE4		AE5	CE5
AE1			AE2			AE3			AE4			AE5		
CE1	*		CE2	*		CE3	*		CE4	*		CE5	*	

(c)

**. The mean difference is significant at 0.05 level.*

In order to investigate the capability of assessing the influence of bonding pattern, the result of MIU and mean coefficient of friction value were analyzed in the case of same fabric weight and component filaments. According to the multiple comparison analysis results, shown in Table 5.3 (a), (b) and (c), it is seen that the resultant tendencies are the same for both method. In nylon spunbond nonwoven fabrics, the minus-pattern and point-pattern spunbond nonwovens have a large friction resistance compared to weave-pattern spunbond nonwovens. In PET spunbond nonwovens, the friction coefficient of minus-pattern spunbond is greater than that of weave-pattern spunbond nonwovens. In nylon spunbond nonwovens, the number of pairwise differences within each group for rotational dragging method (8 pairs) is higher than that of KES (4 pairs). However, the number of pairwise differences for PET spunbond nonwovens is the same in both methods (4 pairwise differences). Therefore, it can be concluded that rotational dragging method is sensitive enough in detecting the effect of bonding pattern on the friction property. Figure 5.8 shows the tendency of the effect of bonding method on the MIU values.

5.5.3. Capability of assessing the influence of component filaments

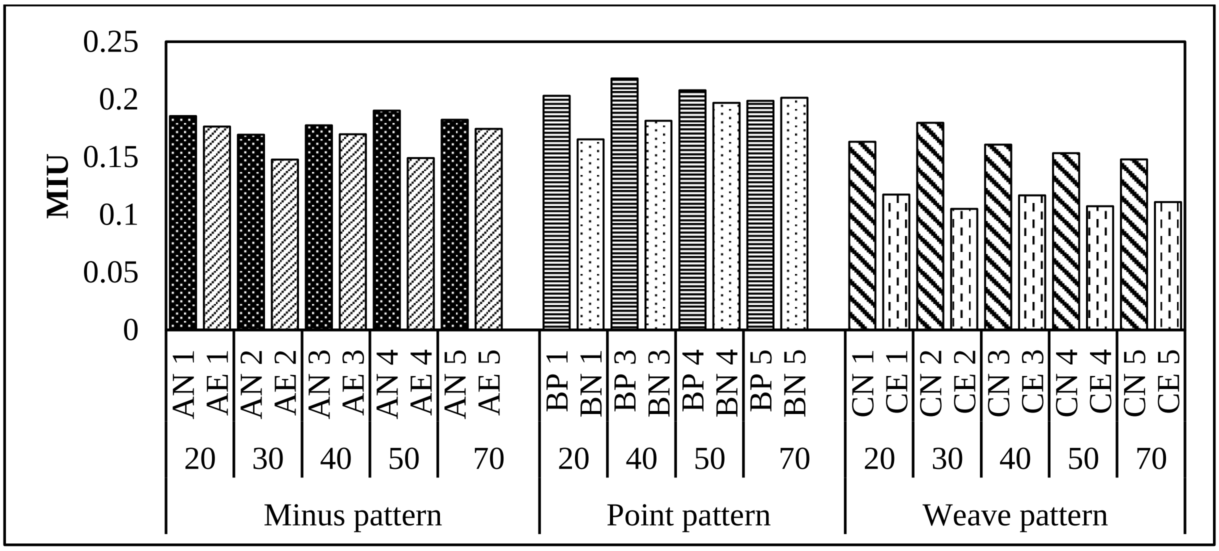


Figure 5.9. Effect of bonding pattern on MIU values

In order to investigate the capability of assessing the influence of component filaments, the result of MIU and mean coefficient of friction value were analyzed in the case of same fabric weight and bonding method. According to the Scheffe test result, shown in Figure 5.9, it is seen that the resultant tendencies are the same for both method. In minus-pattern and weave-pattern bonding, the nylon spunbond has a large friction resistance compared to polyester (PET) spunbond. In point-pattern bonding, the friction coefficient of polypropylene is greater than that of PET spunbond nonwovens. The number of pairwise difference within each group for rotational dragging method is higher than that of KES. In the minus-pattern spunbond nonwoven fabrics, there are 4 pairwise differences in rotatory method whereas only one pair was observed for KES. The number of pairwise differences in point-pattern (2 pairs) and weave-pattern (5 pairs) spunbond is the same for both methods. Therefore, it can be concluded that rotational dragging method is sensitive enough in detecting the effect of fabric density on the friction property. Table 5.4 (a), (b) and (c) show the Scheffee results for MIU.

Table 5.4. The Scheffee test result of MIU for different component filaments

	AN1	AE1		AN2	AE2		AN3	AE3		AN4	AE4		AN5	AE5
AN1			AN2			AN3			AN4			AN5		
AE1	-		AE2	-		AE3	-		AE4	*		AE5	-	

(a)

	BP1	BN1		BP3	BN3		BP4	BN4		BP5	BN5
BP1			BP3			BP4			BP5		
BN1	*		BN3	*		BN4	-		BN5	-	

(b)

	CN1	CE1		CN2	CE2		CN3	CE3		CN4	CE4		CN5	CE5
CN1			CN2			CN3			CN4			CN5		
CE1	*		CE2	*		CE3	*		CE4	*		CE5	*	

(c)

**. The mean difference is significant at 0.05 level.*

5.6. Conclusion

In order to access the capability of a rotational dragging method, the comparative analysis between KES and rotatory method was performed. Although there is a correlation between KES and rotational dragging method, the resultant mean coefficient of friction values of both methods is significantly different from each other. This result is shown in Table 5.5. The reason is that friction is not an inherent property and it comes out when textile rugs textile or another surface. Therefore, the frictional property of textiles depends on the testing method, testing conditions and the material itself. The absolute difference between KES and rotatory dragging method is the type of detector. In KES method, ten numbers of 0.5 mm in diameter piano wires are put together and used as a detector. In rotatory dragging method, a single wire is used as a detector. Therefore, the detector of KES makes surface contact whereas whisker sensor makes a line contact. Moreover, the coefficient of friction in both MD and CD directions are measured while a whisker sensor measures in all directions of the fabric. Additionally, load used for giving compression is different, 50g in KES and 30g in rotational dragging. The relative motion of detector in KES is shown in Figure 5.10.

Table 5.5. Result from Scheffe statistical analysis between KES and Rotational dragging method

	KES	Rotational dragging	Mean difference
PET minus-pattern spunbond	AE 0 KES	AE 0 R	*
	AE 1 KES	AE 1 R	-
	AE 2 KES	AE 2 R	-
	AE 3 KES	AE 3 R	-
	AE 4 KES	AE 4 R	*
	AE 5 KES	AE 5 R	*
Nylon minus-pattern spunbond	AN 1 KES	AN 1 R	*
	AN 2 KES	AN 2 R	*
	AN 3 KES	AN 3 R	*
	AN 4 KES	AN 4 R	-
	AN 5 KES	AN 5 R	*
PP point-pattern spunbond	BP 0 KES	BP 0 R	*
	BP 1 KES	BP 1 R	*
	BP 2 KES	BP 2 R	*
	BP 3 KES	BP 3 R	-
	BP 4 KES	BP 4 R	*
	BP 5 KES	BP 5 R	*
Nylon point-pattern spunbond	BN 1 KES	BN 1 R	*
	BN 3 KES	BN 3 R	*
	BN 4 KES	BN 4 R	*
	BN 5 KES	BN 5 R	*
PET weave-pattern spunbond	CE 1 KES	CE 1 R	*
	CE 2 KES	CE 2 R	*
	CE 3 KES	CE 3 R	-
	CE 4 KES	CE 4 R	*
	CE 5 KES	CE 5 R	-
Nylon weave-pattern spunbond	CN 1 KES	CN 1 R	*
	CN 2 KES	CN 2 R	*
	CN 3 KES	CN 3 R	*
	CN 4 KES	CN 4 R	*
	CN 5 KES	CN 5 R	*

*. The mean difference is significant at 0.05 level.

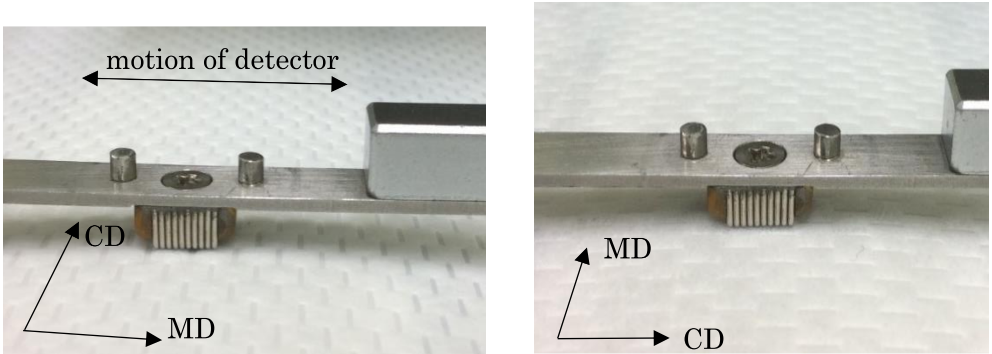


Figure 5.10. Relative motion of KES sensor

To sum up, the whisker sensor friction testing machine has a capability of detection frictional characteristics of spunbond nonwovens. Although it is an another method of objective characterization of spunbond nonwovens, on the other hand, there is still need testing of several samples for establishing a standard testing procedure since the foregoing differences in testing method and/or parameters.

CHAPTER 6
CONCLUSION

Friction between textile to textile and textile to other surface plays a notable role in the control of textile behavior in processing, use and other hand related properties. The frictional property and its influencing factors, therefore, have been carried out at different levels of textile hierarchy: fiber, yarn, and fabric. A number of friction testing methods have been invented and basically, these methods differ from each other in terms of:

i. the nature of contact (point, line or area) and the type of contact (steel, standard fabric)
ii. the relative motion of the contact
iii. the method by which the normal force is applied and the friction force is measured
iv. the environment in which the test is carried out.

Not because of the friction is an inherent property, not only the testing conditions including experimental factors, normal load, testing speed, time of contact but also the characteristics of the material itself influence on it.

There are many literatures in friction property of conventional textiles such as woven and knitted fabrics. Today era, because of bombing in the usage of unconventional textiles, nonwovens, the performance of it in specific use that influenced by friction has become an interesting subject. Therefore, the frictional characteristics of the spunbond nonwovens were investigated in this study.

In the first part of this study, the frictional properties of thermally spunbond nonwovens and its influencing factors were investigated. The test samples differ in mass per unit area, bonding pattern and component filaments. The simple whisker type tactile sensor friction testing machine, developed in my laboratory, was used for detection the coefficient of friction. The working principle of this machine depends on the measurement of strain caused by the friction and compressive forces. When the desired load is applied, the sensor wire trusts on the sample surface and drags over it as soon as the sample stage rotates at constant speed. By which, the resistance of the strain gauge connected to the sensor wire changes relatively with the result friction force and compressive force. As these strain gauges are in the wheat stone bridge, the friction and compressive force can be detected by measuring the output signal of the bridge with the data acquisition system. Hence, the value of friction coefficient is calculated by dividing the friction force and normal force. The advantage of this simple whisker machine is that it can detect the frictional property of fabric surface without considering the specific direction within a short period. Based on the experimental results, it can be concluded as follows.

In general, it is seen that the resultant stick-slip phenomenon changed with the surface geometry of spunbond nonwovens. In minus pattern bonding spunbond, the SSP was regular at 180° of dragging angle by the time the MD of sample and sensor wire are perpendicular than other dragging angles. As a result, the mean deviation of friction coefficient hit the highest at this point. In the weave pattern bonding nonwoven, the regularity of SSP was found at every 90° of trace angle and resulting in the large value of the mean deviation of friction coefficient found at every 90°. In point pattern bonding nonwovens, although there is some regularity in some degree, there is no clear characteristic in its mean deviation trace. Therefore, it can be concluded that the change in surface geometry of spunbond nonwovens can detect during friction measurement with rotational dragging method.

The ANOVA result expressed that the bonding pattern has a significant impact on the frictional property of spunbond nonwoven fabrics in addition to the component filament and fabric density. Generally, the coefficient of friction value was fluctuated in low weight fabric because of surface unevenness. In high density fabrics, the coefficient of friction value increased when the fabric weight increased. This tendency is true for minus-pattern and point-pattern spunbond nonwoven fabrics. But this phenomenon was not true for weave pattern bonding nonwovens. The reason is that not only the influence of fabric density but also the effect of bonding pattern. In the case of same fabric density and constituent filaments, the value of friction coefficient of minus-pattern and point-pattern bonding spunbond is higher than that of weave-bonded-pattern spunbond. The value of friction coefficient of polypropylene nonwoven is higher than that of nylon and nylon spunbond has a high coefficient of friction value compared to polyester spunbond in the case of same bonded pattern and same fabric density.

The standard test method for determining surface characteristics of textiles is Kawabata Evaluation System (KES). The surface tester (KES-FB 4) can measure the friction property of fabric surface in two directions (MD and CD) and the coefficient of friction value is expressed as an average value or MIU value. In order to investigate the capability of rotational dragging method, the comparative study between rotational dragging method and KES was carried out in the second part.

Even though there is a significant difference between these two methods, a high correlation (0.95) was observed especially for weave-pattern spunbond nonwoven fabrics. The correlation values are 0.51 and 0.25 for minus-pattern spunbond nonwoven and point-pattern spunbond nonwoven fabrics respectively. The reason is that difference in nature of detector, surface contact in KES and line contact in whisker sensor, and direction of tracing on the fabric surface, MD and CD and all directions, and the compressive load.

According to the Scheffee result, the number of pairwise difference within each group in rotational dragging was larger than the KES in the minus-pattern and point-pattern spunbond nonwoven fabrics whereas that is the same in both methods in weave-pattern spunbond nonwoven fabrics.

Therefore, it is summarized rotational dragging method is an alternative method to detect the friction property of spunbond nonwoven fabrics objectively. With this method, the frictional characteristics in all directions of nonwoven fabrics can be investigated within a short period by rotational dragging method. Hence, changes in the coefficient of friction value in relative with the dragging direction and surface geometry can be achieved. It is sensitive enough to detect in changing fabric weight, component filaments, and bonding method. Therefore, it can be used in comparing different fabrics. However, doing more experiments is a must-need to establish a standard testing condition. The author believed that obtained results support further research in this area and this alternative method provides an information for who wants to use an easy, accurate and quick alternative method in determining the friction property of nonwoven fabrics.

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APPENDIX A

Table A-1. Values of mean coefficient of friction and mean deviation of all samples

No		Code no.	Fabric density (g/m^2)	mean coefficient of friction	mean deviation
1	Minus pattern	AN 1	20	0.215	0.0173
2		AN 2	30	0.229	0.0207
3		AN 3	40	0.255	0.0212
4		AN 4	50	0.239	0.0235
5		AN 5	70	0.284	0.02613
6		AE 0	15	0.194	0.0162
7		AE 1	20	0.173	0.0161
8		AE 2	30	0.169	0.019
9		AE 3	40	0.181	0.0207
10		AE 4	50	0.215	0.0235
11		AE 5	70	0.217	0.0241
12	Point pattern	BN 1	20	0.194	0.0166
13		BN 3	40	0.23	0.0206
14		BN 4	50	0.22	0.0217
15		BN 5	70	0.238	0.0235
16		BP 0	15	0.266	0.0205
17		BP 1	20	0.366	0.0205
18		BP 2	30	0.265	0.0217
19		BP 3	40	0.234	0.0214
20		BP 4	50	0.246	0.0252
21		BP 5	70	0.443	0.0284
22	Weave pattern	CE 1	20	0.149	0.0158
23		CE 2	30	0.125	0.0169
24		CE 3	40	0.125	0.0175
25		CE 4	50	0.124	0.0175
26		CE 5	70	0.117	0.0173
27		CN 1	20	0.204	0.0169
28		CN 2	30	0.197	0.0196
29		CN 3	40	0.179	0.0207
30		CN 4	50	0.178	0.0223
31		CN 5	70	0.165	0.0254

Table A-2. Shapiro-Wilk test result for mean coefficient of friction

No	Sample	Statistic	df	Sig. (p-value)	No	Sample	Statistic	df	Sig. (p-value)
1	AN 1	0.967	10	0.859	16	BP 0	0.894	10	0.189
2	AN 2	0.942	10	0.572	17	BP 1	0.973	10	0.919
3	AN 3	0.936	10	0.511	18	BP 2	0.798	10	0.014
4	AN 4	0.916	10	0.322	19	BP 3	0.811	10	0.020
5	AN 5	0.929	10	0.440	20	BP 4	0.721	10	0.002
6	AE 0	0.918	10	0.342	21	BP 5	0.936	10	0.512
7	AE 1	0.949	10	0.662	22	CE 1	0.933	10	0.483
8	AE 2	0.951	10	0.675	23	CE 2	0.956	10	0.735
9	AE 3	0.960	10	0.783	24	CE 3	0.941	10	0.569
10	AE 4	0.946	10	0.625	25	CE 4	0.941	10	0.568
11	AE 5	0.956	10	0.744	26	CE 5	0.978	10	0.953
12	BN 1	0.973	10	0.917	27	CN 1	0.975	10	0.930
13	BN 3	0.962	10	0.809	28	CN 2	0.931	10	0.461
14	BN 4	0.914	10	0.308	29	CN 3	0.928	10	0.431
15	BN 5	0.923	10	0.379	30	CN 4	0.873	10	0.109
					31	CN 5	0.957	10	0.756

Table A-3. Skewness and Kurtosis values for mean coefficient of friction

AN 1	Skewness	-0.563	0.687	BP 0	Skewness	1.375	0.687
	Kurtosis	-0.202	1.334		Kurtosis	2.693	1.334
AN2	Skewness	0.599	0.687	BP 1	Skewness	-0.351	0.687
	Kurtosis	-0.734	1.334		Kurtosis	-0.617	1.334
AN 3	Skewness	0.307	0.687	BP 2	Skewness	2.019	0.687
	Kurtosis	-1.347	1.334		Kurtosis	5.059	1.334
AN 4	Skewness	1.073	0.687	BP 3	Skewness	1.641	0.687
	Kurtosis	0.777	1.334		Kurtosis	2.466	1.334
AN 5	Skewness	-0.416	0.687	BP 4	Skewness	1.966	0.687
	Kurtosis	0.081	1.334		Kurtosis	3.76	1.334
AE 0	Skewness	1.077	0.687	BP 5	Skewness	0.087	0.687
	Kurtosis	0.845	1.334		Kurtosis	-1.478	1.334
AE 1	Skewness	0.465	0.687	CE 1	Skewness	0.814	0.687
	Kurtosis	-0.944	1.334		Kurtosis	-0.034	1.334
AE 2	Skewness	0.656	0.687	CE 2	Skewness	0.829	0.687
	Kurtosis	-0.425	1.334		Kurtosis	0.503	1.334
AE 3	Skewness	0.730	0.687	CE 3	Skewness	0.292	0.687
	Kurtosis	0.147	1.334		Kurtosis	-1.274	1.334
AE 4	Skewness	0.727	0.687	CE 4	Skewness	0.737	0.687
	Kurtosis	-0.252	1.334		Kurtosis	-0.221	1.334
AE 5	Skewness	0.663	0.687	CE 5	Skewness	0.028	0.687
	Kurtosis	-0.245	1.334		Kurtosis	-0.848	1.334
BN 1	Skewness	-0.376	0.687	CN 1	Skewness	0.252	0.687
	Kurtosis	-0.739	1.334		Kurtosis	-0.86	1.334
BN 3	Skewness	0.359	0.687	CN 2	Skewness	1.037	0.687
	Kurtosis	-0.991	1.334		Kurtosis	0.906	1.334
BN 4	Skewness	1.023	0.687	CN 3	Skewness	0.684	0.687
	Kurtosis	0.511	1.334		Kurtosis	-0.454	1.334
BN 5	Skewness	1.048	0.687	CN 4	Skewness	1.072	0.687
	Kurtosis	0.717	1.334		Kurtosis	0.061	1.334
				CN 5	Skewness	0.624	0.687
					Kurtosis	-0.054	1.334

APPENDIX B

Table B-1 The MIU values of all samples

No		Fabric weight (g/m^2)	sample	MIU
1	Minus pattern	15	AE 0	0.135275
2		20	AE 1	0.1764
3		30	AE 2	0.14775
4		40	AE 3	0.169725
5		50	AE 4	0.149075
6		70	AE 5	0.1744
7		20	AN 1	0.1855
8		30	AN 2	0.169325
9		40	AN 3	0.177475
10		50	AN 4	0.190217
11		70	AN 5	0.1823
12	Point pattern	15	BP 0	0.198925
13		20	BP 1	0.2031
14		30	BP 2	0.207375
15		40	BP 3	0.218125
16		50	BP 4	0.207875
17		70	BP 5	0.1987
18		20	BN 1	0.1654
19		40	BN 3	0.181325
20		50	BN 4	0.1969
21		70	BN 5	0.2015
22	Weave pattern	20	CE 1	0.1174
23		30	CE 2	0.105
24		40	CE 3	0.116725
25		50	CE 4	0.1073
26		70	CE 5	0.1109
27		20	CN 1	0.1632
28		30	CN 2	0.179675
29		40	CN 3	0.160725
30		50	CN 4	0.153325
31		70	CN 5	0.1479

Table B-2. Shapiro-Wilk test result for MIU

No	Sample	Statistic	df	Sig. (p-value)	No	Sample	Statistic	df	Sig. (p-value)
1	AN 1	0.813	10	0.021	16	BP 0	0.901	10	0.227
2	AN 2	0.941	10	0.564	17	BP 1	0.926	10	0.411
3	AN 3	0.950	10	0.668	18	BP 2	0.932	10	0.469
4	AN 4	0.834	10	0.037	19	BP 3	0.950	10	0.668
5	AN 5	0.905	10	0.251	20	BP 4	0.882	10	0.136
6	AE 0	0.959	10	0.773	21	BP 5	0.936	10	0.509
7	AE 1	0.942	10	0.579	22	CE 1	0.943	10	0.588
8	AE 2	0.956	10	0.740	23	CE 2	0.983	10	0.977
9	AE 3	0.792	10	0.012	24	CE 3	0.873	10	0.109
10	AE 4	0.872	10	0.106	25	CE 4	0.830	10	0.034
11	AE 5	0.976	10	0.938	26	CE 5	0.893	10	0.181
12	BN 1	0.912	10	0.293	27	CN 1	0.802	10	0.015
13	BN 3	0.788	10	0.010	28	CN 2	0.885	10	0.148
14	BN 4	0.767	10	0.006	29	CN 3	0.945	10	0.606
15	BN 5	0.936	10	0.512	30	CN 4	0.971	10	0.898
					31	CN 5	0.935	10	0.495

Table B-3. Skewness and Kurtosis values for MIU

AN 1	Skewness	-0.525	0.687	BP 0	Skewness	-0.7	0.687
	Kurtosis	-1.81	1.334		Kurtosis	-1.86	1.334
AN2	Skewness	-0.562	0.687	BP 1	Skewness	-0.77	0.687
	Kurtosis	-0.498	1.334		Kurtosis	-0.06	1.334
AN 3	Skewness	0.431	0.687	BP 2	Skewness	-0.225	0.687
	Kurtosis	-0.752	1.334		Kurtosis	-0.88	1.334
AN 4	Skewness	0.278	0.687	BP 3	Skewness	-0.29	0.687
	Kurtosis	-2.065	1.334		Kurtosis	-1.14	1.334
AN 5	Skewness	0.507	0.687	BP 4	Skewness	0.63	0.687
	Kurtosis	-0.593	1.334		Kurtosis	-1.25	1.334
AE 0	Skewness	0.26	0.687	BP 5	Skewness	-0.36	0.687
	Kurtosis	-0.98	1.334		Kurtosis	-1.04	1.334
AE 1	Skewness	0.585	0.687	CE 1	Skewness	-0.243	0.687
	Kurtosis	-0.353	1.334		Kurtosis	-0.327	1.334
AE 2	Skewness	0.139	0.687	CE 2	Skewness	-0.185	0.687
	Kurtosis	0.387	1.334		Kurtosis	-0.75	1.334
AE 3	Skewness	-1.338	0.687	CE 3	Skewness	0.99	0.687
	Kurtosis	1.554	1.334		Kurtosis	-0.119	1.334
AE 4	Skewness	-0.659	0.687	CE 4	Skewness	1.27	0.687
	Kurtosis	-0.91	1.334		Kurtosis	0.66	1.334
AE 5	Skewness	0.313	0.687	CE 5	Skewness	0.75	0.687
	Kurtosis	-0.681	1.334		Kurtosis	-0.71	1.334
BN 1	Skewness	-0.43	0.687	CN 1	Skewness	-1.3	0.687
	Kurtosis	-1.38	1.334		Kurtosis	0.431	1.334
BN 3	Skewness	0.98	0.687	CN 2	Skewness	-0.13	0.687
	Kurtosis	-0.88	1.334		Kurtosis	-1.72	1.334
BN 4	Skewness	0.87	0.687	CN 3	Skewness	0.37	0.687
	Kurtosis	-1.29	1.334		Kurtosis	0.85	1.334
BN 5	Skewness	-0.26	0.687	CN 4	Skewness	0.21	0.687
	Kurtosis	-0.32	1.334		Kurtosis	0.52	1.334
				CN 5	Skewness	0.81	0.687
					Kurtosis	0.67	1.334