(REFEREED RESEARCH)

FRICTION COEFFICIENT OF THE SPUNBOND NONWOVENS

SPUNBOND DOKUNMAMIŞ KUMAŞLARDA SÜRTÜNME KATSAYISI

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ABSTRACT

Friction force that can be defined as the force resisting to the movement between two surfaces contacting with each other which plays an important role in textile industry. During usage, the fabrics continue to friction against the textile or other surfaces; because of this problem fabric surface structure deteriorates. Therefore, most scientists have designed different methods in order to estimate surface properties and friction of fabric before usage. In this study, friction experiments have been performed by designing and manufacturing two different systems which work as a horizontal platform and inclined plane. The study has tried to investigate friction properties of polypropylene (pp) nonwoven fabric samples which are produced by spunbond methods (filament laid and thermal bonding) with different weight. While the selected fabric samples weight increase, it has been seen that high friction force becomes effective until a certain weight after when a low friction force occurs because of more stable structure. In addition, it has been observed that the higher is vertical force (load) applied on specimens, the lower coefficient of friction. These results shows that both measurement methods have similar tendencies

Key Words: Nonwoven, Friction force, Coefficient of friction, Surface structure and properties.

ÖZET

Temas halindeki iki yüzey arasındaki bağıl harekete karşı koyan kuvvetler olarak tanımlayabileceğimiz sürtünme kuvvetleri tekstil teknolojisinde çok önemli bir rol oynamaktadır. Kumaşlar kullanım sırasında tekstil olan veya olmayan çeşitli yüzeylere sürtünmeye devam etmekte ve bu durum onların aşınmasına ve eskimesine neden olmaktadır. Bu yüzden kumaş yüzey ve sürtünme özelliklerinin kullanım öncesinde tespit edilmesi amacıyla birçok araştırmacı çeşitli metotlar geliştirerek ölçümler yapmışlardır. Bu çalışmada, tasarımı ve imalatı yapılmış olan yatay platform ve eğik düzlem prensiplerine göre çalışan iki farklı sistem kullanılarak sürtünme deneyleri yapılmıştır. Çalışmada numune olarak kullanılan spunbond yöntemi (filament serme ve ısıl bağlama) ile üretilmiş farklı gramajlardaki dokunmamış kumaşların sürtünme özellikleri incelenmeye çalışılmıştır. Seçilen numunelerde gramaj arttıkça daha stabil bir yapı kazandıkları ve bunun sonucunda sürtünme katsayısının belli bir gramaja kadar arttığı ve daha sonra da azalmaya başladığı gözlenmiştir. Ayrıca numune üzerine etkileyen düşey yöndeki kuvvet (yük) arttıkça sürtünme katsayısında bir azalma eğiliminin olduğu tespiti de yapılmıştır. Bu sonuçların kullanılan her iki yöntemde de benzer eğilimde oldukları görülmüştür.

Anahtar Kelimeler: Dokunmamış kumaş, Sürtünme kuvveti, Sürtünme katsayısı, Yüzey yapısı ve özellikleri.

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1. INTRODUCTION

Fabrics that will be used in technical fields are generally chosen based on their performance characteristics such as tensile strength, extension ability, tear resistance, friction and abrasion, some chemical resistance, etc according to where they are used. However, when choosing fabrics for dress-making, their brightness, surface smoothness or evenness, softness-hardness, solidness, drapery and some other appearance and handle features are preferred over their technical characteristics. Above mentioned fabric handle properties are evaluated on subjective basis by textile businesses and people experienced in fabric trading. These properties not also affect the treatment and dress-making process of fabrics; they also affect the appearance and comfort of personal wearing. However, the fact that it is subjectively assessed by people makes it difficult to examine and measure handle, which further complicates the concept of handle (1).

In this area, Ramkumar et al., prepared a new friction test environment by adding new apparatuses to the Instron Tensile Testing Device so that surface mechanical features of the cotton knitted fabric could be analyzed. As a result of the study, it has been observed that loop length and yarn density affect fabric-to-fabric friction features. It has been mentioned that as loop length increases, so does friction coefficient. Moreover, it has been suggested that yarn linear density also plays an important role in determining friction coefficient in addition to loop length (2). Hirai and Gunji, conducted a study on determination of friction coefficient by Slip Meter device which is developed by JSMA (Japan Shoe Manufacturers Association) using seven different types of carpets. In this study, it has been observed that as the contact area applied by the shoe on the carpet increases, so does friction coefficient value. It has been emphasized that friction also depends on the material structure of the shoe bottom and it has been suggested that bottom made of synthetic rubber has lower friction values compared to those of leather bottom (3). Fontaine et al., established a testing mechanism known as tribometer which works on blade-disk principle. In the study, nonwoven fabrics of different weights produced by spunbond and spunlace methods were dry tested. As a result, it was emphasized that as weight decreases, so does surface roughness for fabrics made of same type of raw materials. The reason of this phenomenon was stated as surface status, compression density and polymer type used (4). Lima et al., applied standard metallic surface-fabric and fabric-fabric friction tests on cotton woven fabrics of different types using a newly developed device known as FrictorQ. As a result, they observed that standard metallic surface-fabric friction coefficient were lower than the fabric-fabric friction coefficient (5). Su et al., examined the effect of nano-Al_2O_3 and nano-Si_3N_4 particles applied on carbon fibers on friction and wear characteristics. Friction and wear tests were measured with pin-on-disk device which consisted of stainless steel disk, electrical furnace, thermocouple and pin. In the study, it was found out that as nano-Al_2O_3 and nano-Si_3N_4 content in carbon fabrics increased, friction coefficient value decreased. It was stated that, with nano-Al_2O_3 and nano-Si_3N_4 particles added to carbon fabrics, tribiological characteristics of fabrics improved (6). In another study conducted in this subject, Kalebek and Babaarslan, examined friction and softness characteristics of nonwoven fabrics produced with spunbond and spunlace methods. A conventional universal tensile tester device was modified according to the purpose of that study and a new testing environment was prepared. At the end of the study, it was observed that high values of friction coefficient for nonwoven fabrics with similar physical features had a softer handle (7).

In this study, friction tests have been applied on nonwoven fabric specimens produced with different weighted polypropylene-based spunbond technique with testing devices that work on two different principles. As a result of this study, it has been observed that fabric weight and the force applied on fabric are two effective parameters on fabric-fabric friction coefficient of the nonwoven fabrics.

2. MATERIAL AND METHOD

2.1. Material

In this study, 100% polypropylene nonwoven fabric specimens produced with spunbond technique have been used as testing material. Specimens have been tested according to Textiles-Test Methods for Nonwovens-Part 3: Determination of Tensile Strength and Elongation; ISO 9073-3;1989 and Textiles-Test Methods for Nonwovens-Part 4: Determination of Tear Resistance; ISO 9073-4;1997 standard (8,9) under convenient conditions, and values given in Table 1 have been obtained. These tests have been applied so as to determine some of the physical characteristics of nonwoven fabrics that are used for sampling purposes.

Table 1. Physical properties of nonwoven fabric samples

Fabric Weight (g/m^2)	Thickness (mm)	Tensile Strength (N/5 cm)		Elongation (%)		Tear Resistance (N/5 cm)	
		MD	CD	MD	CD	MD	CD
20	0,155	65.0	52.0	65.0	66.0	20.0	21.0
30	0,200	90.0	76.0	70.0	65.0	30.0	30.0
70	0,360	123.5	111.3	48.2	48,9	60.0	65.0
85	0,420	167.7	143.5	49.1	49.6	65.0	68.0
100	0,460	200.0	163.0	70.0	71.0	82.0	85.0

These fabrics have been used as protective coatings, disposable diapers, hygiene sanitary napkins, operating gowns and also furniture and bedspeads, carpet backs, geotextiles, agriculture products and industrial protective clothes. Therefore, friction coefficient of nonwoven fabrics appears is an important factor in most of these usage areas.

2.2. Method

For the purpose of this study, frictional properties of nonwoven fabrics have been tested by using two different working principle devices. These devices are named as “Horizontal Platform Experiment Device” and “Inclined Plane Experiment Device” (7, 10, 11).

2.2.1. Horizontal Platform Experiment Device

It is the mechanism shown in figure 1 which was developed by designing and extra changes upon conventional universal tensile tester in order to perform friction experiments. The designed and manufactured device consists of anti-friction rollers [3,4], non-stretch yarn [5], a sled [6] and a sled bed [7]. A Non-stretch yarn [5] is passed through rollers [3,4] to upper carrier claw [1] of tensile tester. Fastening the sample to the circular sled [6] made of circular 50 mm in diameter delrin material is ensured by using a clip in proper dimensions. Nonwoven fabric [10] sample which is covered on sled [6] is laid out in the same direction with horizontal platform.

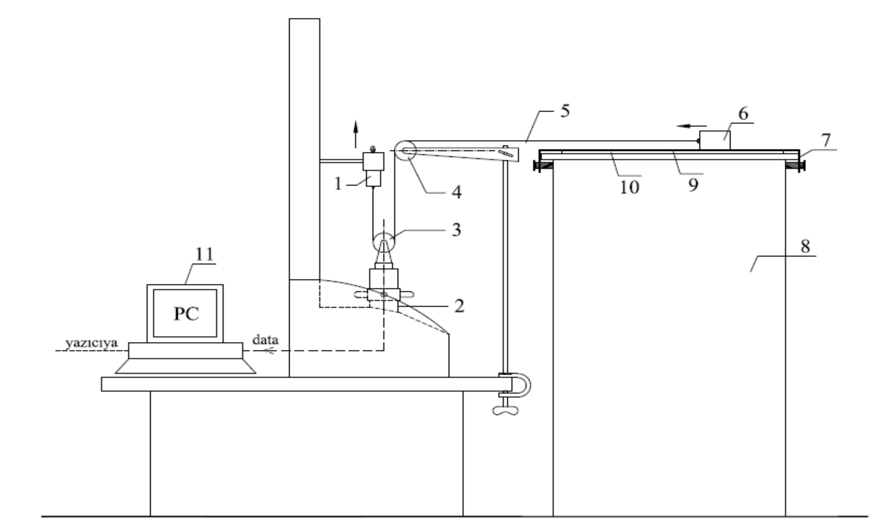

Figure 1. Horizontal platform experiment device (7, 10)

(1. Upper Carrier Claw, 2. Load Cell, 3,4. Anti-Friction Roller, 5. Non-stretch Yarn, 6. Sled, 7. Sled Bed, 8. Experiment Table, 9. Sponge, 10. Fabric, 11. Computer)

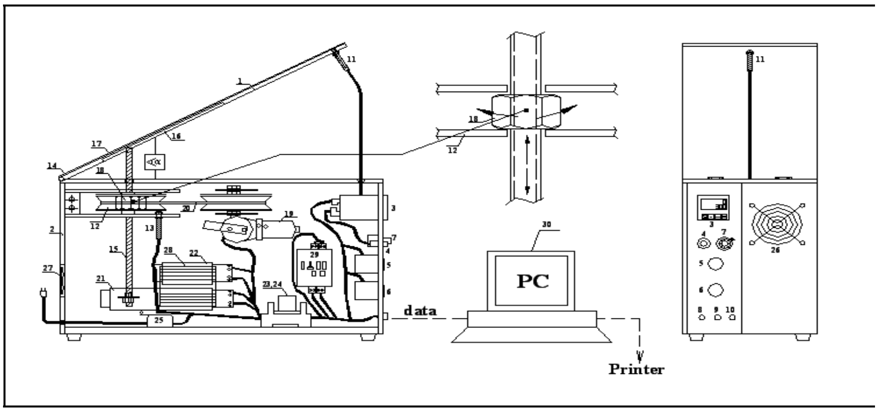

Figure 2. Inclined plane experiment device (11)

(1. Platform, 2. Main Frame, 3. Programmable Impulse Counter, 4. Reset Button, 5. Up-Control Button, 6. Down-Control Button, 7. Motor Speed Controller Rheostat, 8. Command Fuse, 9. Impulse Counter Fuse, 10. Motor Fuse, 11. Metal Detector- PNP Φ12 mm, 12. Drum, 13. Metal Detector - PNP Φ8 mm, 14. Magnet, 15. Screw, 16. Canal, 17. Metal, 18. Loaf, 19. Motor, 20. Belt, 21. Motor-Transformer 220/12V, 100 VA, 22. Controller Transformer 220/12V, 50 VA, 23. Role Ry (Upward), 24. Role Ra (Downward), 25. Downward Switch, 26. Fresh Air Window, 27. Fan, 28. Aluminum Coolers, 29. Electronic Circle, 30. Computer)

Sled bed [7] is designed with the aim of stretching the fabric [10] on experiment table [8] so as to hold it stable and to prevent slipping, curling, twisting or folding during the experiment. While the upper carrier claw [1] of developed device is moving at a specific speed, it also pulls delrin sled [6] and as a result a friction occurs between two surfaces. At the same time, the load changes stemming from fabric surface structure created during the movement are perceived by load cell [2] and created in graphical and numerical values by the computer [11].

2.2.2. Inclined Plane Experiment Device

Another design which explains relationship between frictional coefficient and textile surfaces is running with an object slides on a textile surface principle. The platform [1] and the main frame [2] of the designed and prototypal manufactured laboratory equipment which is running with a inclined plane principle is made of wood (Figure 2). Programmable impulse counter EMKO EZM 4430 [3], reset button to reset this counter [4], up-control button [5], down-control button [6], motor speed controller rheostat-100 kΩ [7], command fuse-220V/2A [8], impulse counter fuse-220V/2A [9] and motor fuse-220V/3A [10] are mounted on the main frame of the equipment. Command control buttons [5,6] are responsible for moving the platform [1] up and down. When pushed to the up control button [5] once, the platform [1] starts moving upwards, and when counter-side action is requested pushing down control button [6] once will be enough. Once up button is pushed, the platform [1] moves upward and down button is pushed if the platform [1] is demanded to move downward. The metal detector - PNP φ12 mm [11] which is assembled on the platform [1] transfers the movement (tour) it perceives in each 30 degrees thanks to the metals of the metal detector - PNP φ8 mm [13] on the surface of the drum to EMKO EZM 4430 [3], which is an impulse counter. This data obtained via these processes can directly give the "*tanα*" i.e. the value of interplane coefficient of friction with the help of the computer program.

3. TEST RESULTS AND EVALUATION

For the purpose of this study, frictional properties of nonwoven fabrics have been tested by using two different working principle devices. All tests have been conducted in a controlled environment with a temperature of 20±2 °C and relative humidity of % 65±5.

3.1. Test Performed on Horizontal Platform Experiment Device

Frictional behavior tests have been performed with 5 different loads (7.4, 10.2, 14.5, 17.3 and 20.2), two fabric directions, namely Machine Direction (MD) and Cross Direction (CD) and 3 different points of samples. As a result of friction tests, the highest value at the beginning of movement has been accepted as static friction resistance; the mean of values read afterwards has been accepted as kinetic friction resistance. Attention was paid to make sure that the specimen placed on horizontal platform and the specimen

Table 2. Test results conducted experimental device that works horizontal platform principle

Weight (g/m²)	Applied Force (N)	Coefficient of Friction Values			
		μ_s (Static)		μ_k (Kinetic)	
		MD	CD	MD	CD
20	**7.4**	1.229	1.312	1.184	1.199
	10.2	1.104	1.210	1.000	1.115
	14.5	0.953	1.007	0.928	0.984
	17.3	0.894	0.983	0.878	0.879
	20.2	0.830	0.965	0.808	0.756
30	**7.4**	1.312	1.328	1.150	1.172
	10.2	1.207	1.275	1.140	1.157
	14.5	1.047	1.102	1.030	1.100
	17.3	1.001	1.100	0.957	0.964
	20.2	0.942	0.969	0.930	0.951
70	**7.4**	1.315	1.348	1.173	1.201
	10.2	1.210	1.287	1.161	1.194
	14.5	1.205	1.245	1.150	1.160
	17.3	1.143	1.166	1.126	1.132
	20.2	1.112	1.158	1.087	1.100
85	**7.4**	0.991	1.242	0.943	0.956
	10.2	0.910	1.105	0.848	0.857
	14.5	0.873	0.959	0.837	0.845
	17.3	0.835	0.943	0.797	0.808
	20.2	0.749	0.824	0.651	0.725
100	**7.4**	0.783	0.825	0.746	0.784
	10.2	0.738	0.801	0.733	0.739
	14.5	0.716	0.783	0.725	0.731
	17.3	0.707	0.729	0.694	0.706
	20.2	0.676	0.698	0.693	0.694

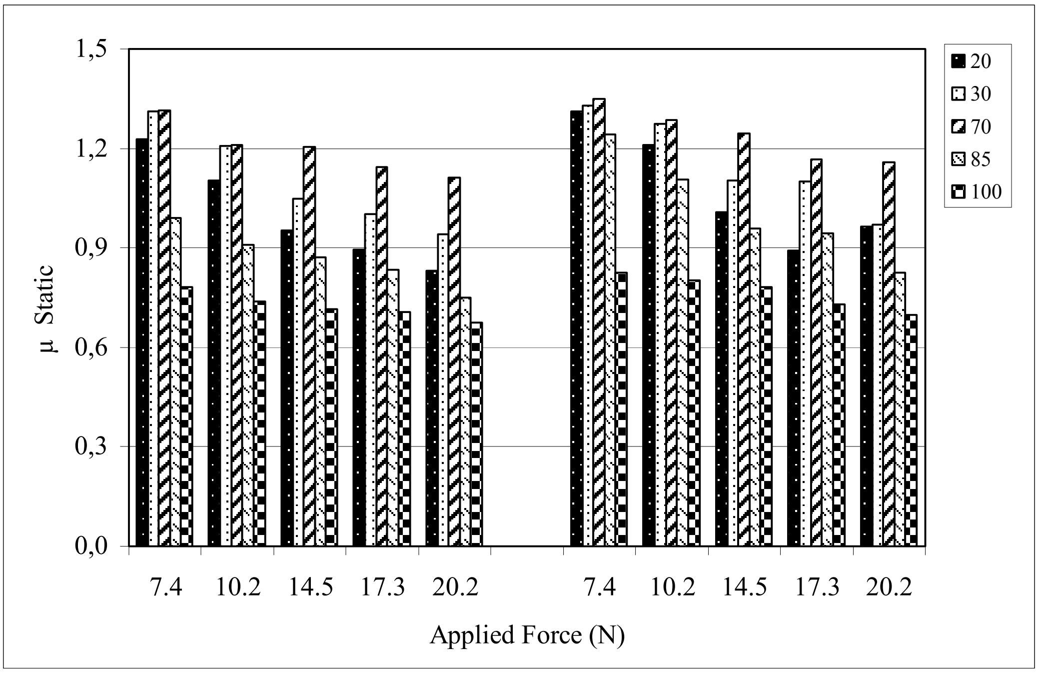

Figure 3. Changes in static coefficient of friction versus applied normal force for different fabric weight at experimental devices that works horizontal platform principle

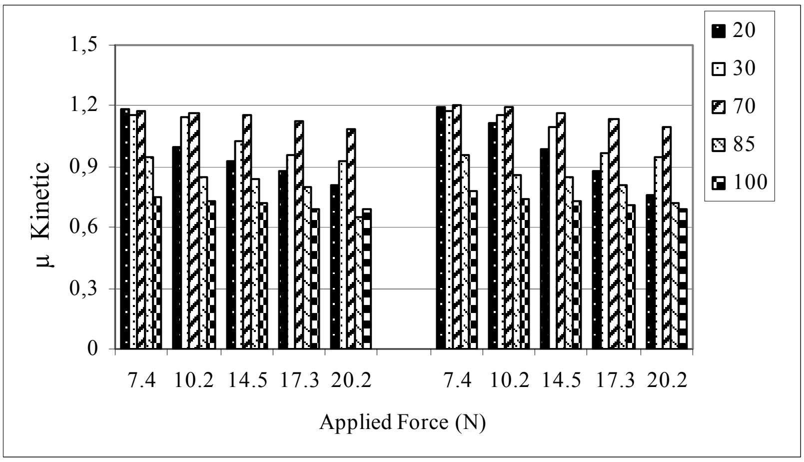

Figure 4. Changes in kinetic coefficient of friction versus applied normal force for different fabric weight at experimental devices that works horizontal platform principle

Table 3. Test results experiment device that works inclined plane principle

Weight (g/m^2)	**Applied Forces (N)**	**μ (Coefficient of Friction)**	
		MD	**CD**
20	**7.4**	0.400	0.412
	10.2	0.390	0.404
	14.5	0.345	0.358
	17.3	0.313	0.325
	20.2	0.300	0.309
30	**7.4**	0.490	0.587
	10.2	0.467	0.532
	14.5	0.432	0.516
	17.3	0.415	0.419
	20.2	0.406	0.417
70	**7.4**	0.898	0.965
	10.2	0.817	0.879
	14.5	0.804	0.815
	17.3	0.735	0.765
	20.2	0.712	0.739
85	**7.4**	0.725	0.790
	10.2	0.715	0.787
	14.5	0.799	0.710
	17.3	0.729	0.747
	20.2	0.702	0.723
100	**7.4**	0.721	0.780
	10.2	0.718	0.779
	14.5	0.710	0.750
	17.3	0.708	0.745
	20.2	0.709	0.700

attached to delrin part are slightly strained and fabric rubbed to different parts of the fabric. Figures 3 and 4 have been obtained using the friction coefficients obtained from the tests, which are given in table 2.

It has been observed that nonwoven fabrics with higher fabric weight have lower friction coefficient compared to fabrics with lower fabric weight. One interpretation for its reason is that fiber placement/orientation in low-weight samples are not distributed evenly. Another observation is that, when delrin sled is forced to move/slide on fabric surface, it is met with more resistance when moving in MD direction than in CD direction. It has

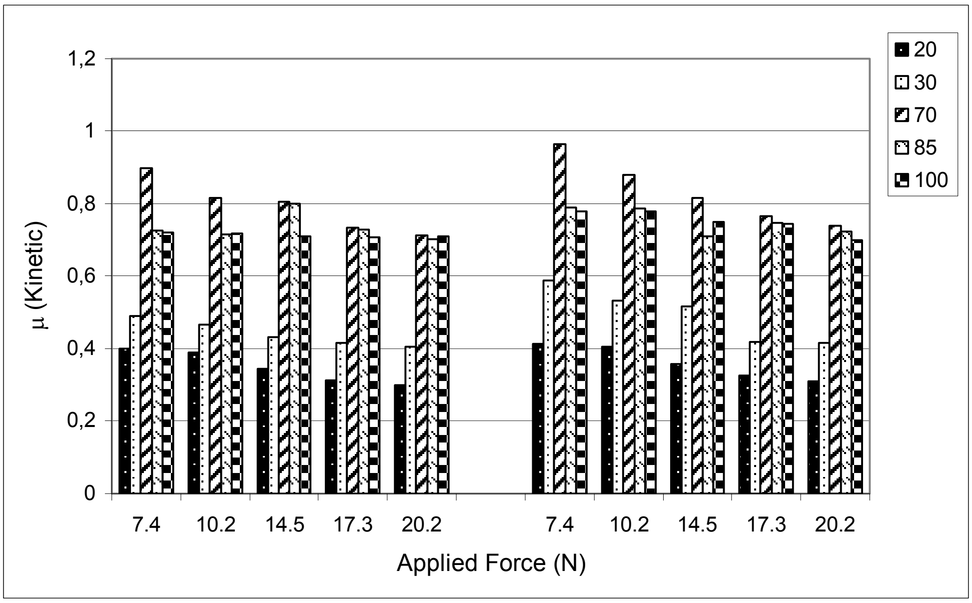

Figure 5. Changes in kinetic coefficient of friction versus applied normal force for different fabric weight at experimental devices that works inclined plane principle

been observed that static friction coefficients are usually higher than kinetic friction coefficients. In addition, the figures suggest that as the load applied on specimens increases (normal force F_n), static and kinetic friction coefficient decreases in tests applied in MD and CD directions, the reason of which is attributed to the fact that, as the force applied on fabric specimen increases, compression, flatting and therefore relative smoothening of fabric surface is observed.

3.2. Tests conducted on inclined plane experiment device

In test mechanism that works on inclined plane principle, platform floor of the device has been covered with nonwoven fabric specimens placed in MD and CD directions while the upper dynamic delrin part has been coated with nonwoven fabric specimens of similar characteristics in MD and CD directions. Thus, test environment has been prepared for fabric-fabric friction.

Three tests in MD direction, three tests in CD direction and tests under five different loads (7.4, 10.2, 14.5, 17.3, 20.2 N) have been applied for each specimen. As a result of the friction tests, the value of the peak point at the beginning of the movement has been accepted as static friction resistance. As the resistance after the movement begins cannot be fully perceived in inclined plane experiment device, emphasis has been put on only kinetic friction coefficient. The data obtained after measurements, which are given in table 3, are used to obtained figure 5.

When figure 5 is examined, it can be seen that as weight increases, friction coefficient decreases in nonwoven fabrics. This situation is similar to the friction behavior results conducted in horizontal platform experiment device. It can be concluded that results obtained using same fabric specimens with two different methods are comparable and both methods can be readily used for this purpose. Friction coefficient values of specimen in CD direction have been found higher than the values in MD direction. In addition, it has been observed that the change in friction coefficient against the force (load) applied on specimens has similar tendencies in both measurement methods. This finding shows that different methods introduced here yield fit-for-purpose results that confirm each other.

4. STATISTICAL ANALYSIS

4.1. An analysis of the results obtained using horizontal platform experiment device

Variance analysis at α = 0.05 significance level has been conducted on the data obtained from experimental studies using Design Expert 6.0.1. statistical package program. Obtained ANOVA tables and model graphics are summarized below, where a (p) value under 0.05 means that evaluated factor has a significant impact.

During statistical analysis, fabric direction, which affects physical and mechanical features, was taken as categorical factors (by name), and weight and applied force were taken as numerical (digital) factors.

When the ANOVA table (Table 4) is examined, it can be seen that fabric weight (A), applied force (B) and fabric direction (C) of nonwoven fabrics have significant impact on the friction coefficient values. In addition, when the interaction between and within factors A, B and C are examined, it can be said that weight (B^2), applied force and fabric direction (BxC), and fabric direction (C^2) have significant impacts, whereas weight and applied force (AxB), and weight and fabric direction (AxC) do not have any significant impact.

In lack of fit test, the model with highest p value must be chosen. Accordingly, the quadratic model with 0.9342 p value was chosen, which can be seen from table 5.

Table 4. Anova table (results obtained on the horizontal platform experiment device)

Factor	Sum of Squares	Degree of Freedom	Mean Squares	F value	Prob>F	
Model	1.79	8	0.22	84.36	<0.0001	Significant
A	0.064	1	0.064	24.18	<0.0001	Significant
B	0.57	1	0.57	213.32	<0.0001	Significant
C	0.35	1	0.35	133.19	<0.0001	Significant
B^2	0.74	1	0.74	277.93	<0.0001	Significant
C^2	0.038	1	0.038	14.36	0.0005	Significant
AB	1.053E-005	1	1.053E-005	3.968E-003	0.9501	Not significant
AC	1.140E-003	1	1.140E-003	0.43	0.5162	Not significant
BC	0.093	1	0.093	35.11	<0.0001	Significant
Total	1.89	47				
R-Squared: 0.9454 Adj R-Squared:0.9342						

(A: Fabric Weight , B: Applied Force, C: Fabric Direction)

Table 5. Model summary statistics

Source	Sum of Squares	Degree of Freedom	Mean Squares	F Value	P Value
Linear	1.01	3	0.34	16.61	0.4990
2FI	0.046	3	0.015	0.75	0.4902
Quadratic	**0.74**	**2**	**0.37**	**139.24**	**0.9342**
Cubic	3.902E-003	7	5.574E-004	0.18	0.9228

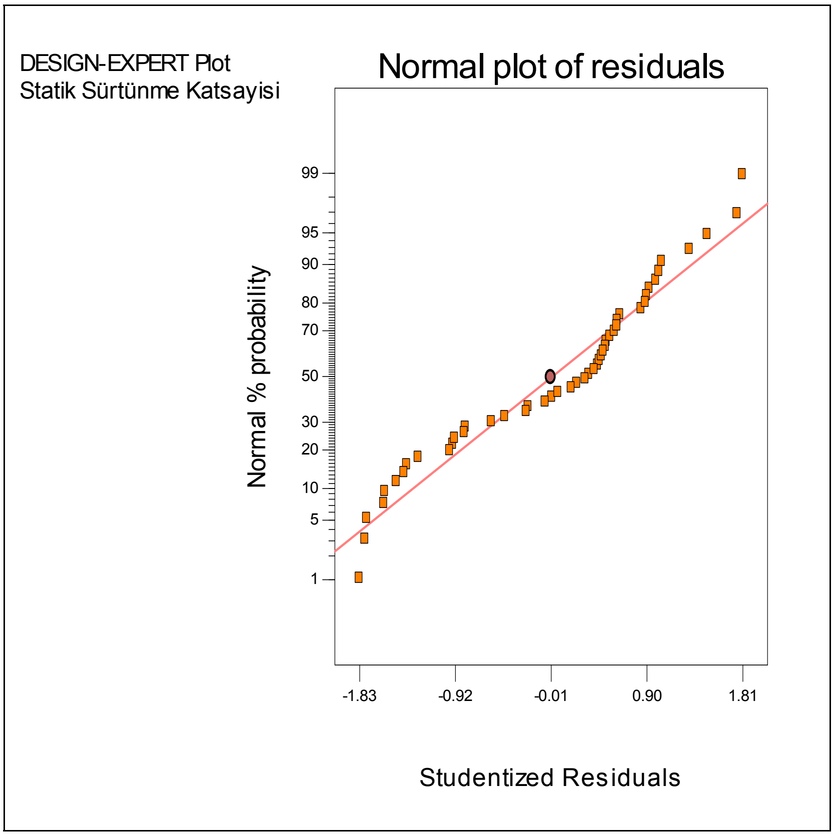

Figure 6. Normal plot of residual static coefficient of friction values

Table 6. Anova table (results obtained on the horizontal platform experiment device)

Factor	Sum of Squares	Degree of Freedom	Mean Squares	F value	Prob>F	
Model	1.29	8	0.16	47.59	<0.0001	Significant
A	2.954E-003	1	2.954E-003	0.87	0.3559	Not Significant
B	0.49	1	0.49	144.95	<0.0001	Significant
C	0.18	1	0.18	53.14	<0.0001	Significant
B^2	0.60	1	0.60	178.15	<0.0001	Significant
C^2	0.012	1	0.012	3.60	0.0653	Not Significant
AB	1.372E-003	1	1.372E-003	0.41	0.5281	Not Significant
AC	7.087E-004	1	7.087E-004	0.21	0.6498	Not Significant
BC	0.12	1	0.12	34.35	<0.0001	Significant
Total	1.42	47				
R-Squared: 0.9071 Adj R-Squared:0.8880						

(A: Fabric Weight , B: Applied Force, C: Fabric Direction)

Table 7. Model summary statistics

Source	Sum of Squares	Degree of Freedom	Mean Squares	F Value	P Value
Linear	0.63	3	0.21	11.64	0.3852
2FI	0.056	3	0.019	1.04	0.4061
Quadratic	**0.60**	**2**	**0.30**	**89.24**	**0.8880**
Cubic	0.019	7	2.678E-003	0.76	0.6269

Residuals are checked for analyzing deviations (residuals) from the model. It is concluded that, if deviations in the model draw an almost straight line, normality (normal distribution) assumption is acceptable. Figure 6 gives normal distribution graph of residuals for Quadratic Model. As can be told from the figure, no problems are observed in normal distribution in the chosen model. This analysis also supports the conformity of chosen model.

Explanatory percentage of the model which confirms data, R^2, has to be calculated. According to table 4, R^2 value of the model turned out to be approximately 0.95, in which case the terms in the model can be explained almost 95%. This case shows that the model established for friction coefficient describes the relation between dependent variables and independent variables with a considerably high accuracy and that experimental study is accepted as accurate.

Likewise, variance analysis at α = 0.05 significance level has been conducted on the data obtained from experimental studies for kinetic coefficient of friction using Design Expert 6.0.1. statistical package program. Obtained ANOVA tables and model graphics are summarized below, where a (p) value under 0.05 means that evaluated factor has a significant impact.

When the ANOVA table (Table 6) is examined, it can be seen that applied force (B) and fabric direction (C) of nonwoven fabrics have significant impact, whereas weight (A) does not have a significant impact on the friction coefficient values. In addition, when the interaction between and within factors A, B and C are examined, it can be said that applied force (B^2) and applied force and fabric direction (BxC) have significant impact, whereas fabric direction (C^2), weight and applied force (AxB) and weight and fabric direction (AxC) do not have significant impact.

In lack of fit test, the model with highest p value must be chosen. Accordingly, the quadratic model with 0.8880 p value was chosen, which can be seen from table 7.

Figure 7 gives normal distribution graph of residuals for Quadratic Model. As can be seen from the figure, no problems are observed in normal distribution in the chosen model. This analysis also supports the conformity of the chosen model.

Explanatory percentage of the model which confirms data, R^2, has to be calculated. According to table 6, R^2 value of the model turned out to be some 0.88, in which case the terms in the model can be explained almost 88%. This case shows that the model established for friction coefficient describes the relation between dependent variables and independent variables with a considerably high accuracy and that experimental study is accepted as accurate.

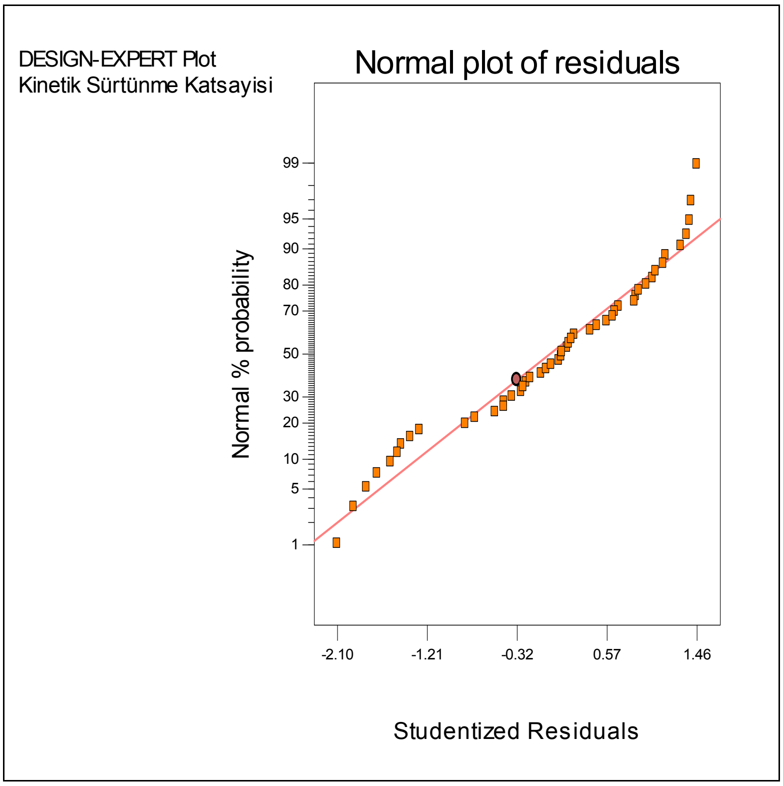

Figure 7. Normal plot of residual kinetic coefficient of friction values

Table 8. Anova table (results obtained on the inclined plane experiment device)

Factor	Sum of Squares	Degree of Freedom	Mean Squares	F value	Prob>F	
Model	5.07	8	0.63	289.50	0.0001	Significant
A	3.46	1	3.46	1579.79	0.0001	Significant
B	0.18	1	0.18	80.52	0.0001	Significant
C	0.035	1	0.035	16.08	0.0003	Significant
A^2	0.72	1	0.72	328.83	0.0001	Significant
B^2	$3.65*10^{-3}$	1	$3.65*10^{-3}$	1.67	0.2041	Not Significant
AB	0.074	1	0.074	33.85	0.0001	Significant
AC	$7.92*10^{-4}$	1	$7.92*10^{-4}$	0.36	0.5508	Not Significant
BC	$8.918*10^{-3}$	1	$8.918*10^{-3}$	4.07	0.0505	Not Significant
Total	5.16	47				
R-Squared: 0.9834 Adj R-Squared:0.9800						

(A: Fabric Weight , B: Applied Force, C: Fabric Direction)

4.2 An analysis of the results obtained using horizontal platform testing mechanism

Variance analysis at α = 0.05 significance level has been conducted on the data obtained from experimental studies using Design Expert 6.0.1. statistical package program. Obtained ANOVA tables and model graphics are summarized below, where a (p) value under 0.05 means that evaluated factor has a significant impact.

When the ANOVA table (table 8) is examined, it can be seen that weight (A), applied force (B) and fabric direction (C) of nonwoven fabrics have significant impact on the friction coefficient values. In addition, when the interaction between and within factors A, B and C are examined, it can be said that weight (A^2) and weight and applied force (AxB) have significant impacts, whereas applied

Table 9. Model summary statistics

Source	Sum of Squares	Degree of Freedom	Mean Squares	F Value	P Value
Linear	0.92	43	0.021	2.24	0.4926
2FI	0.82	40	0.020	2.15	0.5006
Quadratic	**0.076**	**38**	**1.997E-003**	**0.21**	**0.9647**
Cubic	0.053	31	1.701E-003	0.18	0.9755

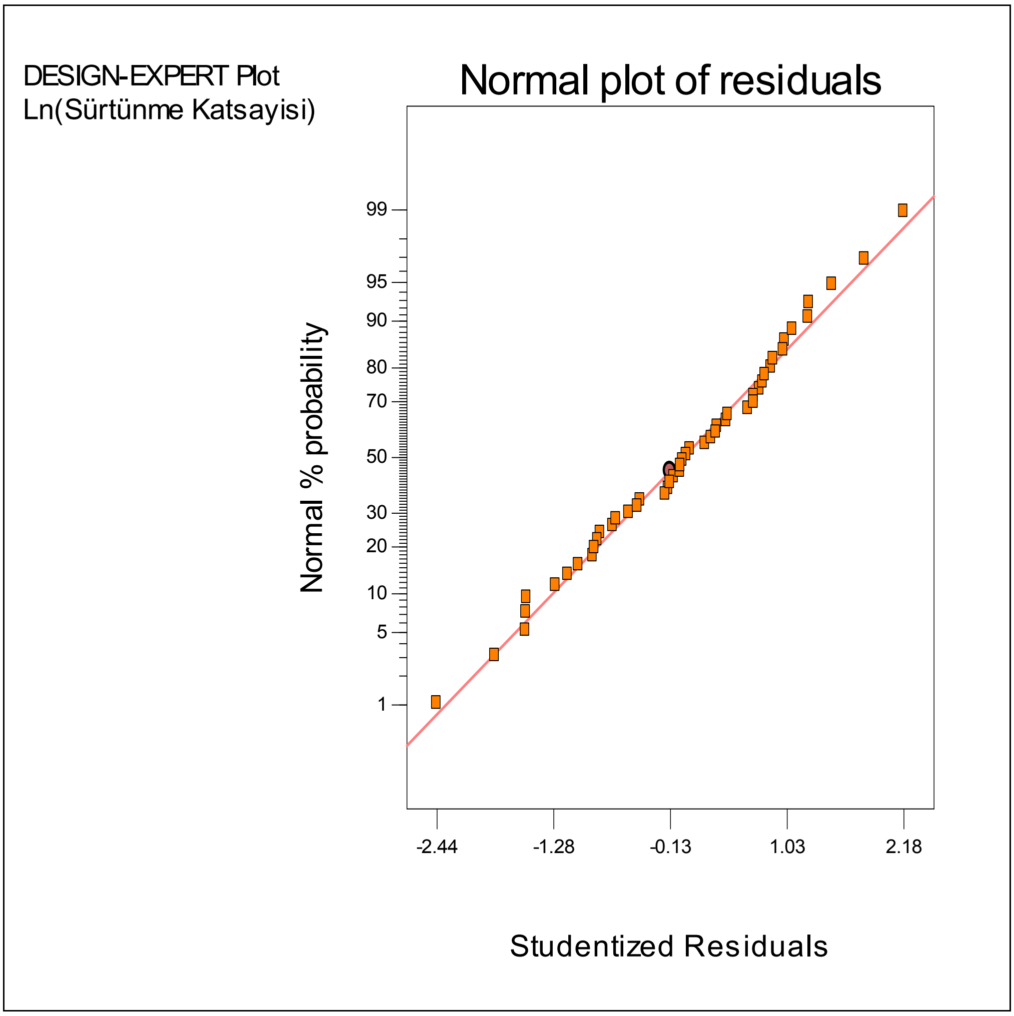

Figure 8. Normal plot of residual coefficient of friction values

force (B^2), weight and fabric direction (AxC) and applied force and fabric direction (BxC) do not have significant impact.

As a fit test does not exist, the model with highest p value must be chosen. Accordingly, the quadratic model with 0,9647 p value was chosen, which can be seen from table 9.

Figure 8 gives normal distribution graph of residuals for Quadratic Model. As can be seen from the figure, no problems are observed in normal distribution in the chosen model. This analysis also supports the conformity of the chosen model.

Explanatory percentage of the model which confirms data, R^2, has to be calculated. According to table 8, R^2 value of the model turned out to be approximately 0.98, in which case the terms in the model can be explained almost 98%. This case shows that the model established for friction coefficient describes the relation between dependent variables and independent variables with a considerably high accuracy and that experimental study is accepted as accurate.

5. CONCLUSION

Many researchers have developed new devices and methods in order to fully determine the interaction of surface structure of textile materials with each other and with other materials. The most important reason of this situation is lack of a test standard and device which can objectively measure some sensory characteristics like fabric handle. From this viewpoint, design of systems that work on two different principles related to the study topic was completed and prototypes were manufactured. Friction tests have been applied to nonwoven fabrics on these devices. Results obtained by the experimental study are summarized below:

- Applied force, weight, production method, and raw material are parameters that affect friction behaviors. Determination of friction characteristics of textile surfaces (woven, knitted and nonwoven) can be evaluated as an important criterion for ensuring aesthetic and comfort of surface.
- It has been concluded from examined fabrics that, as applied normal load increases, friction coefficient tends to decline in both systems. As the pressure on fabric specimen increases, it leads to compression, flattening and relative smoothening of fabric surface, which decreases friction coefficient.
- Test results show that, as weight increases, nonwoven fabrics with more stable structure have lower friction coefficient.
- In tests conducted with two different systems, friction coefficients have been found as lower in MD direction of the fabric than in the CD direction, which is attributable to the fiber/filament settlement at the fabric formation stage.

The purpose of this study was to obtain results which can be understood, applied and repeated in uniformity by everyone so as to determine surface and handle properties of fabrics based on various methods. It is believed that obtained test results and devices which are designed and manufactured provide an important database for all researchers and industrialists who want to determine the frictional properties of fabrics, as well as supporting further research in this area.

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