(REFEREED RESEARCH)

AN INVESTIGATION ON SOUND GENERATION IN DIFFERENT FABRICS

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ABSTRACT

Fabric sound is comprised as fabric handle property such as fabric softness, stiffness and drape. As the previous studies were reviewed, it could be seen that, in general different sound generation systems were used in which the fabric was pulled in a constant velocity. In these measurement systems, a fabric sample was rubbed against the face of another fabric sample and the friction occurred face to face. However, in some actions, friction is not always face to face. There are several different movements (such as jogging) and friction types in which the physical properties such as friction, roughness, shear, and bending stiffness act important role on fabric sound. In order to imitate all these situations, “waving movement sound” was designed. In addition to this, “frictional movement sound” was also defined and used to compare waving movement sound with the common (caused by face to face friction) frictional sound.The aim of this study is to investigate the sound generation properties of the fabrics under the influence of different frictions and movements. For this purpose, three different commonly used woven fabrics and three military windcheater fabrics were used and “Level Pressure of Total Sound (LPT)” values of these were measured during “frictional movement” and “waving movement”. According to the results, since frictional movement created higher friction force, LPT values of the frictional movement was found higher than the LPT values of waving movement. Higher bending rigidity and higher kinetic friction coefficient (μ) values increase frictional sound. In conclusion, smoother, thinner and softer surfaces supply lower LPT values in both “frictional movement” and “waving movement” sounds.

Keywords: Waving sound, frictional sound, fabrics rustle sound, acoustic property, tactile property, fabric handle.

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1. INTRODUCTION

Fabric sound is an important parameter of the sensorial comfort. It is generated as the fibers or fabrics are rubbed against one another during the movement of the wearer such as walking, jogging, and running[1,2] and it changes the purchasing preferences of consumers[3]. Since many consumers are gradually interested in the sensorial quality of clothing, auditory sensibility products have recently been expected to broaden the textile and clothing market[4].

Sound of the clothes can cause different effects according to the application area. For example, silk fabric has a pleasant sound beside its superior properties. On the other hand, sounds of suiting fabrics could be considered as a defect in fabric quality. Moreover, in military area, undesirable sound of a military windcheater could have a vital importance for a soldier[5].

Fabric sound has been studied by several researchers by using various methods such as Fast Fourier Transform analysis and The Kawabata evaluation system (KES)[1]. In some of these studies, fabric sound and its relationships with the fabric structural factors and auditory sensation were researched[6].

The sound and tensile characteristics of woven fabrics by using Fast Fourier Transform Analysis and Kawabata's KES-FB system by Yi and Cho (2000). A sound generator for objective and reproducible simulation of fabric rustles was developed in this study. According to the results, LPT (level pressure of total sound) value was found higher for the fabrics that had higher shear properties[5].

Comfort and fabric handle characteristics of various lining fabrics were investigated by McCullough (1999). Grading scale from 0 to 15 was used and panelists evaluated the fabric handle subjectively. Noise intensity and noise pitch were the searched sound characteristics and they were evaluated by placing the samples close to the ear, compressing and rotating them gently. It was concluded that acetate linings generated slightly more sound compared to the polyester linings[7].

Kim et al. (2003) investigated the sound characteristics of twill polyester fabrics which were produced from fibers in different cross-sectional shapes including round, hollow, triangular, u-shape, cruciform, and composite cross-sections. According to the results, the hollow shaped fiber had the highest value of LPT, whereas the triangular shaped fiber had a lower value[2].

The term "Loudness" corresponds to sound pressure level (level pressure of total sound-LPT) and it is the major parameter affecting human sensation[6]. Yi and Cho (2000) studied the sound characteristics of 25 different fabrics consisted of wool, cotton, silk, polyester and nylon fibers. According to the results, wool fibers indicated higher loudness than cotton, while sharpness values were higher for wool fiber group than other fibers[5].

Kim et al. (2003) studied the sound characteristics and mechanical properties of polyester warp knitted fabrics according to the construction type. According to the results the open lap construction was found louder, sharper, and had larger fluctuation strength than the closed lap[8].

Cho and Cho (2012) compared the frictional sounds of PU-Nanoweb and PTFE film laminated fabrics and investigated the relationship among sound characteristics, mechanical properties and conditions of PU Nanoweb and PTFE film such as thickness and weight. Variables for minimizing the frictional sound were suggested [9].

In most of the studies, a constant frictional speed was used to generate fabric noises. However, the speed was much slower than that occurring in our daily life. For this reason, all these studies were limited in considering a fabric sound according to speeds of the wearer's activities in various dynamic situations. Yang et al. (2009) conducted a motion analysis to identify fabric frictional speeds between the arm and the trunk while walking, jogging, and running to simulate the frictional sound of fabric under conditions similar to real life, and analyzed the acoustic properties of frictional sound of fabric [10].

Fabric frictional sounds of the specimen were measured by Park and Cho (2012) with a measuring apparatus for fabric noise. Sound parameters were obtained by the sound quality system, while KES-FB system was used for mechanical property measurements. Linear regression analysis was used to suggest the equations to predict the acoustic properties using mechanical properties. According to the correlation analysis, the two sets of variables from mechanical properties and acoustic characteristics had high correlation [11].

An innovative frictional sound automatic measuring system (FSAMS) was designed and used by Wang et al. (2017) and the frictional sound was investigated when natural-fiber woven fabrics are rubbed together. The automatic FSAMS were compared with those from a manual frictional sound measuring system. The primary purpose of this instrument is to generate fabric friction sounds during the fabric-fabric friction. It was stated that, the background noise should be less than 10 dB when operating the manual FSAMS [12].

The purpose of this study is to compare the level pressure of total sound (LPT) values of the selected fabrics during frictional and waving movements and to analyze the relationship between the sound characteristics and the fabric properties including circular bending rigidity and kinetic friction coefficient.

2. MATERIALS AND METHODS

2.1. Fabrics

Three different military fabrics were used in windcheaters and three different commercially available woven fabrics were used in the experiment. Fabrics named as "Camouflage Fabrics" consist of 3 layers which are a warp knitted structure (a structure produced from 80 denier polyester yarn), a polyurethane coating (a membrane layer in 25 µm thickness) and a camouflage printed plain woven fabric. Second fabric group named as "Woven Fabrics" is also woven in plain weave structure and made of cotton yarn. Basic structural properties of the studied fabrics are given in Table 1.

2.2. Sound Measurement

Fabrics were tested in a sound insulated room, as given in Fig. 1a, which has 20 ºC temperature and 55% RH . LPT values of the fabrics were measured by sound level meter (Fig. 1b) and measurements were repeated 3 times. Each test continued during 31 seconds by taking 2 measurements in a second (Totally 186 measurements were taken during the test conducted by each operator). The distance between the sound level meter and the fabric was kept constant at 1 m and the results were recorded as dB(A) values.

Table 1. Structural Properties of the Fabrics

Fabric code	Fabric Type	Yarn Count (Weft)	Yarn Count (Warp)	Weft Density (picks/cm)	Warp Density (ends/cm)	Mass per Unit Area (g/m2)	Thickness (mm)
1	Camouflage Fabrics	70 x 2 denier (For camouflage printed woven outer surface)	70 denier	25	40	182	0,40
2			80 denier	25	40	190	0,43
3			90 denier	25	40	200	0,46
4	Woven Fabrics	Ne 20	Ne 20	22	24	150	0,34
5		Ne 16	Ne 20	22	24	180	0,38
6		Ne 12	Ne 20	22	24	210	0,43

(a) (b)

Figure 1. Sound Insulated Room (a), DeltaOHM HD2010 UC/A Integrating Sound Lever Meter Portable Analyzer (b) [13]

2.3. Sound Generation

Different sound generation systems were used by several researchers in the previous studies. In these experiments, it is pointed out that fabric rubbing action occurs in a constant velocity and a face of a fabric sample is rubbed to the other fabric sample in which the friction occurs face to face. However, in some actions, friction is not always face to face. Since, fabric sound is related with some of the physical properties such as friction, roughness, shear, and bending stiffness[14], different movements and friction types should also be considered. Unfortunately, there is not a standard test method for these different movements. For this reason, two different movement methods were designed to generate different sounds, which were defined as “frictional movement sound” and “waving movement sound”. “Frictional movement sound” simulates the sound created in textile materials during the friction of two textile surfaces, for example inner surface of the legs of the trousers. Frictional sounds generated by the friction of two textile materials were investigated in the previous researches.

In this study, “waving movement sound” was designed in order to simulate especially the sound generated in the junction of trousers. In this sound generation movement, there also exists shear forces apart from the frictional forces and this type of sound has not been simulated yet. Both movements were created by hand motions of three operators. By this way, background noise which would be caused due to the friction of the elements of mechanical devices was eliminated.

Since the sound generation was generated by hand motion, the repeatability of the movements generated by each operator needed to be confirmed. Therefore, each operator made both these movements and Level Pressure of Total Sound values of the fabrics were recorded every day during ten days. Thereafter “Grubbs Test” was conducted for the measured results of each operator to control the repeatability and confidence of the results.

2.3.1. Frictional Movement Sound

In this movement method, sound was obtained by the frictional movement of the fabric, which is given in Fig. 2. In this movement, fabric (30 cm x 30 cm) was held by two edges (a) and folded (b). Thereafter, right and left hands were moved up (c) and down (d). Thus, sound was generated by the friction on the face side of the fabric.

By this method, it is aimed to simulate the sound, which is generated by the friction around armpits and inner part of the garments. For this purpose, fabrics cut in the dimensions of 30 cm x 30 cm were used during the measurement. Each piece was held and moved back and forth, which is illustrated in Fig. 2. Duration of each back and forth movement took about 1 second and the sound pressure level was recorded for 31 seconds.

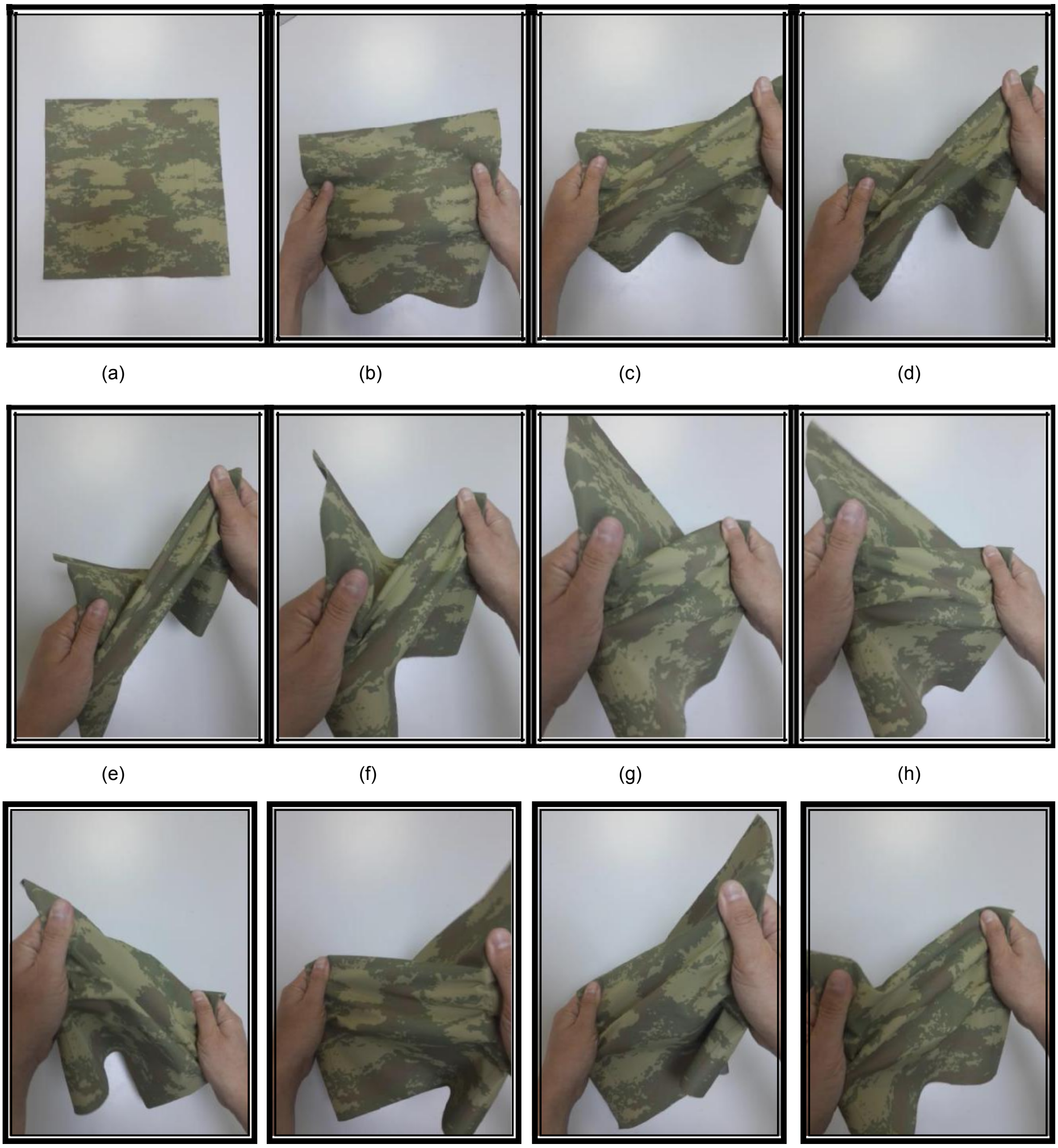
2.3.2 Waving Movement Sound

Fabric sounds are the result of complex interactions that include sliding friction but also crumpling sounds due to buckling of the fabric on itself[15]. “Waving Movement” was designed to simulate the deformation and the movements in clothes during jogging and running. In this movement method, the fabric samples (30 cm x 30 cm) were held 5 cm away from fabric edge and then waved to deform the fabric which is given in Fig. 3. The movements of the hands seem as pedaling.

Duration of each cycle takes about 1 second and the sound pressure level was recorded for 31 seconds. Both of the movements were done by hand, but by 3 different persons. To test the repeatability and reliability, the first fabric (180 g/m^2 camouflage fabric) was tested for both type of movements and the tests were conducted in different days for 10 times for each person. To check the test results, Grubb’s test was conducted, which is a statistical method used to detect outliers in a univariate data set assumed to come from a normally distributed population.

(a) (b) (c) (d)

Figure 2. Obtaining Frictional Movement Sound



(a) (b) (c) (d)

(e) (f) (g) (h)

(ı) (i) (k) (i)

Figure 3. Obtaining Waving Movement Sound

Grubb's statistic:

Grubb's high: $$G = \frac{X_{max} - \overline{X}}{S} \quad (1)$$

Grubb's low: $$G = \frac{\overline{X} - X_{min}}{S} \quad (2)$$

where,

xmax : the maximum value in the data set,

xmin : the minimum value in the data set,

: the sample mean

S : the sample standard deviation

For the two-sided test, the hypothesis of no outliers is rejected at significance level α if

$$G > \frac{N-1}{\sqrt{N}}\sqrt{\frac{t^2_{\alpha/(2N),N-2}}{N-2+t^2_{\alpha/(2N),N-2}}}$$

with $t_{\alpha/(2N),N-2}$ denoting the upper critical value of the t-distribution with *N- 2* degrees of freedom and a significance level of α/(2*N*) [16].

According to the Grubbs test (Table 2), the calculated "Grubb's low" and "Grubb's high" results of each operator were not found higher than the tabulated critical value in Grubbs table value (2.29; for α =0.05). Therefore, the p value is found higher than 0.05 and the difference between the remaining values is not statistically significant. As a result, movements made by hand provided repeatability and reliability for three different operators.

Table 2. Grubb's Test Results

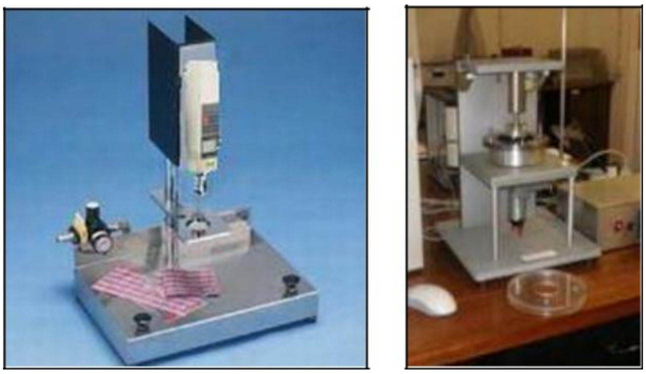
	1st Operator		2nd Operator		3rd Operator	
N=10	**Frictional Movement Sound**	**Waving Movement Sound**	**Waving Movement Sound**	**Waving Movement Sound**	**Waving Movement Sound**	**Waving Movement Sound**
Mean	59,45	50,71	60,16	51,30	61,66	51,95
Standard Deviation	2,88	0,72	2,76	1,47	2,33	2,18
Minimum	56,14	49,7	56,00	49,50	57,00	49,00
Maximum	64,7	51,8	64,50	54,00	65,00	54,00
Grubb's low	*1,15*	*1,40*	1,51	1,23	2,00	1,35
Grubb's high	*1,82*	*1,51*	1,57	1,84	1,43	0,94
Grubb's table value	**2,29**	2,29	2,29	2,29	2,29	2,29

In addition to this, in order to determine whether there is a significant difference between the measurement results of three different operators, test values were evaluated statistically by variance analysis method and the related p values are given in Table III. According to the results, it can be seen that difference between the results were found statistically insignificant.

2.4. Stiffness and Frictional Properties Measurement

There are several studies that investigated the relationship between fabric sound properties and hand feel properties. According to the studies of Cho et al. (2001), the sound "level range" was found to exhibit a positive correlation with sensed softness and pleasantness[15,17]. In addition to this, roughness was also found as a parameter that strongly correlated with the perceived pleasantness of fabric sounds [15, 18].

Since stiffness and surface properties have influence on fabric sound, these two handle properties were also investigated in the experiment. Circular bending rigidity of the fabrics were measured according to ASTM 4032 standard by using SDL ATLAS Digital Pneumatic Stiffness Tester (Fig. 4a). Frictorq instrument (Fig. 4b) that uses the torq principle was used in order to determine the kinetic friction coefficient of the experimental fabrics.



(a) (b)

Figure 4. Circular bending rigidity tester (a), Frictorq instrument (b) [19,20]

Table 3. ANOVA Results for the values measured from 1st , 2nd and 3rd person

Comparison Between Operators for each Fabric Type	Frictional Movement Sound Sig.	Waving Movement Sound Sig.
Fabric 1	0,236	0.295
Fabric 2	0,449	0.324
Fabric 3	0,498	0.059
Fabric 4	0.090	0.142
Fabric 5	0.484	0.188
Fabric 6	0.442	0.278

3. RESULTS AND DISCUSSION

3.1. Circular Bending Rigidity Test Results

Test results for the circular bending rigidity of the fabrics are given in Fig. 5. According to the test results and statistical evaluation results (Table 4), it can be denoted that, the fabric rigidity increases with the increasing fabric weight.

In case of fabric type, camouflage fabrics have comparatively higher rigidity than the woven fabrics. The stiffness of a fabric is very dependent on its thickness. The thicker the fabric, the stiffer it is [21]. For this reason, it is thought that, this result is related with the higher thickness of the camouflage fabrics.

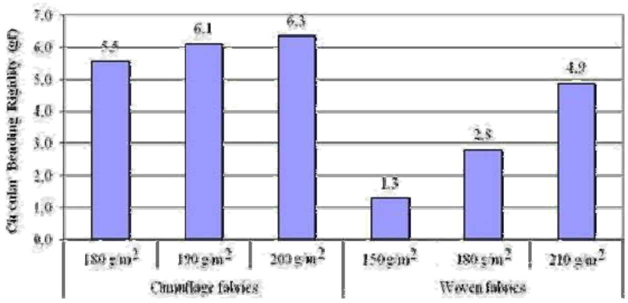


Figure 5. Circular Bending Rigidity Test Results

3.2. Kinetic Friction Coefficient Results

As kinetic friction coefficient values were compared (Fig. 6 and Table 4), it is clearly seen that, camouflage fabrics have lower kinetic friction coefficient, therefore they give a smoother feeling than the woven fabrics.

Fabric friction arises from the asperities on the fabrics surfaces interacting and interlocking with the same asperities on the opposing fabric surface. Threads of woven fabrics influence friction as the yarn diameter increased. The surface area of fabrics is quantified by a fabrics surface roughness and an increase in surface roughness leads to a higher level of friction. In addition to yarn diameter, aperture size also has a marked effect on surface area and an increase in surface roughness leads to a higher level of friction[22]. As the fabric density increases, aperture size decreases. For this reason, due to the higher weft density of the camouflage fabrics, smoother surfaces were obtained.

In case of fabric weight, it can be pointed out that, as fabric weight increases, μ values also increase in both fabric groups. It is resulted from the thicker yarns used in the structure. Thicker yarns form a rougher surface and therefore higher μ values were obtained.

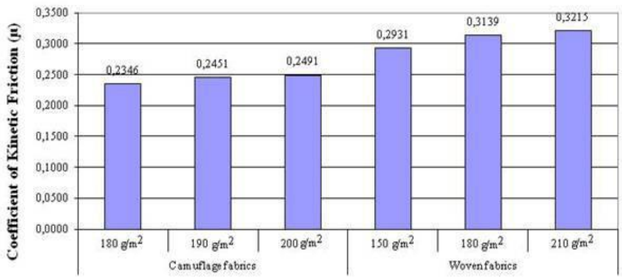


Figure 6. Coefficient of Kinetic Friction Test Results

3.3. Results for Fabric Sound

Level pressure of total sounds measured during frictional and waving movements are given in Fig. 7 and the statistical evaluation results can be seen in Table 5.

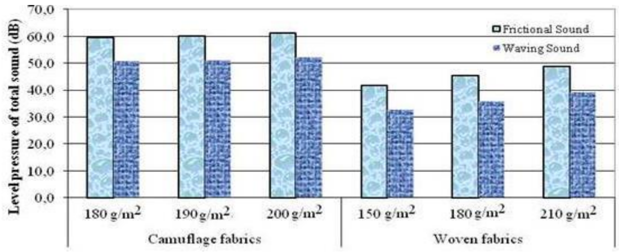


Figure 7. Level Pressure of Total Sound

According to the results, it can be stated that LPT value of the fabrics increases, as the fabric weight increases. The difference between the values was found statistically significant (Table 5). Besides, friction movement sound is significantly higher than the waving movement sound in all fabric types. It is due to the high friction force between contact surfaces, which is generated during the frictional movement. However in waving movement, shear, bending and torsional deformation are distinctive and they generate comparatively lower friction force and lower sound.

The lowest LPT values were obtained from the woven fabrics. It is determined that thicker the fabric, higher the fabrics sound.

Relationship between the results of circular bending rigidity, kinetic friction coefficient properties and sound characteristic of the fabrics were also examined. Pearson correlation coefficients were calculated and given in Table VI. As the results were analyzed, it can be seen that circular bending rigidity and kinetic friction coefficient highly correlate with both frictional and waving sounds of the fabrics.

When circular bending rigidity of the material is higher, the material is stiffer and both frictional and waving sounds are found higher.

As the kinetic friction coefficient results are evaluated in two fabric groups individually, it can be stated that higher the kinetic friction coefficient, higher the fabric sound. However, as all test results are considered together, it is determined that, camouflage fabrics generate much higher fabric sound, although they have lower friction coefficient, which is a result of higher thickness value of the camouflage fabrics.

Table 4. Multiple Comparison Test (SNK) Results for circular bending rigidity and coefficient of friction

Fabric Type		N	Results of Circular Bending Rigidity					Results of Coefficient of Kinetic Friction				
			Subset					Subset				
			1	2	3	4	5	1	2	3	4	5
Camouflage Fabrics	180 g/m^2	3	5,5333					0,2346				
	190 g/m^2	3		6,1000					0,2451			
	200 g/m^2	3		6,3333					0,2491			
Woven Fabrics	150 g/m^2	3			1,3000					0,2931		
	180 g/m^2	3				2,8333					0,3139	
	210 g/m^2	3					4,8667					0,3215
Sig.			1,000	0,365	1,000	1,000	1,000	1,000	0,202	1,000	1,000	1,000

Table 5. Multiple Comparison Test (SNK) Results for Level Pressure of Total Sound (dB)

Fabric Type		N	Results of Frictional Movement Sound						Results of Waving Movement Sound					
			Subset						Subset					
			1	2	3	4	5	6	1	2	3	4	5	6
Camouflage Fabrics	180 g/m^2	558	59,4475						50,7415					
	190 g/m^2	558		60,0361						51,1678				
	200 g/m^2	558			61,2361						52,1678			
Woven Fabrics	150 g/m^2	558				41,7623						32,8016		
	180 g/m^2	558					45,4328						35,8066	
	210 g/m^2	558						48,6828						39,3066
Sig.			1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

Table 6. Pearson correlation coefficients between fabric properties

TESTED PARAMETERS	Frictional Movement Sound		Waving Movement Sound	
	Pearson correlation coefficient	Sig. (2-tailed)	Pearson correlation coefficient	Sig. (2-tailed)
Circular Bending Rigidity	0.939*	0.006	0.931*	0.007
Kinetic Friction Coefficient	-0.858**	0.029	-0.872**	0.024
** Correlation is significant at the 0.01 level (2-tailed)*		***Correlation is significant at the 0.05 level (2-tailed).*		

4. CONCLUSION

Fabric rustling sound is an important handle property for both military fabrics and for some garments and fabrics have specific sound levels. Several researchers used various objective sound measurement systems by using friction occurring in a constant velocity and between faces of two fabrics. They are generally designed as fabric-fabric friction in low velocity levels. However, there are various types of activities in which roughness, shear, and bending stiffness affect sound property. In order to simulate both types of sound generation, two different movement methods were designed to generate different sounds, which were defined as “frictional movement sound” and “waving movement sound” in the study. In addition to this, it is a significant point not to increase background noise during generating fabric sound. By using hand motions during generation of fabric sound, background noise caused by the mechanical devices to create fabric hand is eliminated.

The aim of this study is to compare the sound levels of various fabrics during waving and frictional movements. For this purpose, six different fabrics were used and following results were obtained.

- Waving movement sound was designed to simulate sound generation during activities such as running and walking and in this respect; it is thought that the results will be useful to explain this type of sound generation in selected woven fabrics better.
- LPT values of the frictional movement was found higher than the LPT values of waving movement, due to the higher friction forces created during frictional movement. Higher friction causes higher vibration and higher sound.
- Fabric kinetic friction coefficient and circular bending rigidity increase with the increasing fabric mass. Correlation analysis indicated that, circular bending rigidity and kinetic friction coefficient highly correlate with frictional and waving sounds of the fabrics.
- Higher bending rigidity and higher μ value increase frictional sound, for this reason lower sound values could be obtained by using smoother, thinner and softer surfaces.

5. ACKNOWLEDGEMENT

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