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Experimental determination of the frictional characteristics of fabrics made of natural silk

Umme Kapanyk

Southwestern University "Neofit Rilski" – Blagoevgrad, Bulgaria

umi12@abv.bg

Abstract. Natural silk fabric is directly derived from insect produced cocoons containing large volumes of fibroin protein. The fibroin fibres secreted by the two silk glands of Bombyx mori are smooth and soft and form the structural center of silk. Sericin is a coating with an amorphous structure that bonds the two strands. It is the component hardening the raw thread. The fabric as we know it with low mass per unit area. The level of friction of textile materials depends on a number of test factors - normal load, contact surface area, friction speed, as well as the nature of the textile surface and the direction of friction - warp - warp, warp – weft. In this study, four types of fabric made of 100% natural silk have been examined. They all have different characteristics for mass per unit area, weave, density and linear density of the warp and weft threads. The study makes use of appliance tribometer MXD -02, from Labthink, China to determine the values of static and dynamic friction coefficients. Friction is conducted in different directions and under different pressure. This experimental study has clearly showed that silk fabrics with higher surface mass - display friction coefficient values (at rest and in sliding) greater than 1. Friction index and friction coefficient are influenced by the test direction where friction index in warp direction of one fabric with parallel arrangement of the threads is higher compared to threads in weft direction of another fabric.

1. Introduction

A number of technological problems in the sewing industry, incl. layering, cutting, subsequent separation, sewing, packaging, etc. are related to the coefficients of friction of the layers of fabrics in each other.

Next, the user's subjective perception of fabric friction is an important factor, however, touch is not a method for quantifying the friction process. The quantitative parameters of fabric friction, as well as the factors that influence the process are important in the world of textile technologies. The level of friction of textile materials depends on a number of test factors - normal load, contact surface area, friction speed, as well as the nature of the textile surface and the direction of friction - warp - warp, warp - weft.

The surface properties of woven fabrics largely follow their structure [13]. They acquire a plane orientation depending on the mutual contact between the warp and weft threads [11].

Silk fabrics are characterised by low surface mass. This is due to the finesse of the silk threads. The natural silk thread is composed of two proteins - fibroin (about 70-80%) and sericin (20-30%).

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The fibroin fibres secreted by the two silk glands of Bombyx mori are smooth and soft and form the structural center of silk. Sericin is a coating with an amorphous structure that bonds the two strands [1]. Sericin is the component hardening the raw thread (Fig. 2).

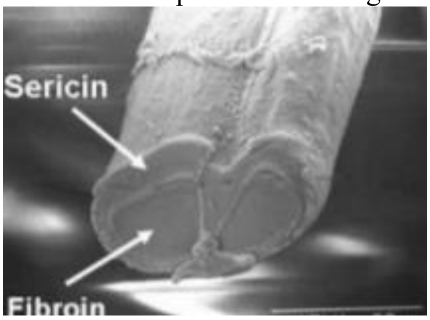


Figure 1. Construction of silk thread [2].

2. Experimental part

The research for the present work is performed using four textile materials made of 100% natural silk. The studied textile fabrics have different characteristics. They are produced by company "Svila" AD, Haskovo. Their specific parameters are listed in table. 1 [3].

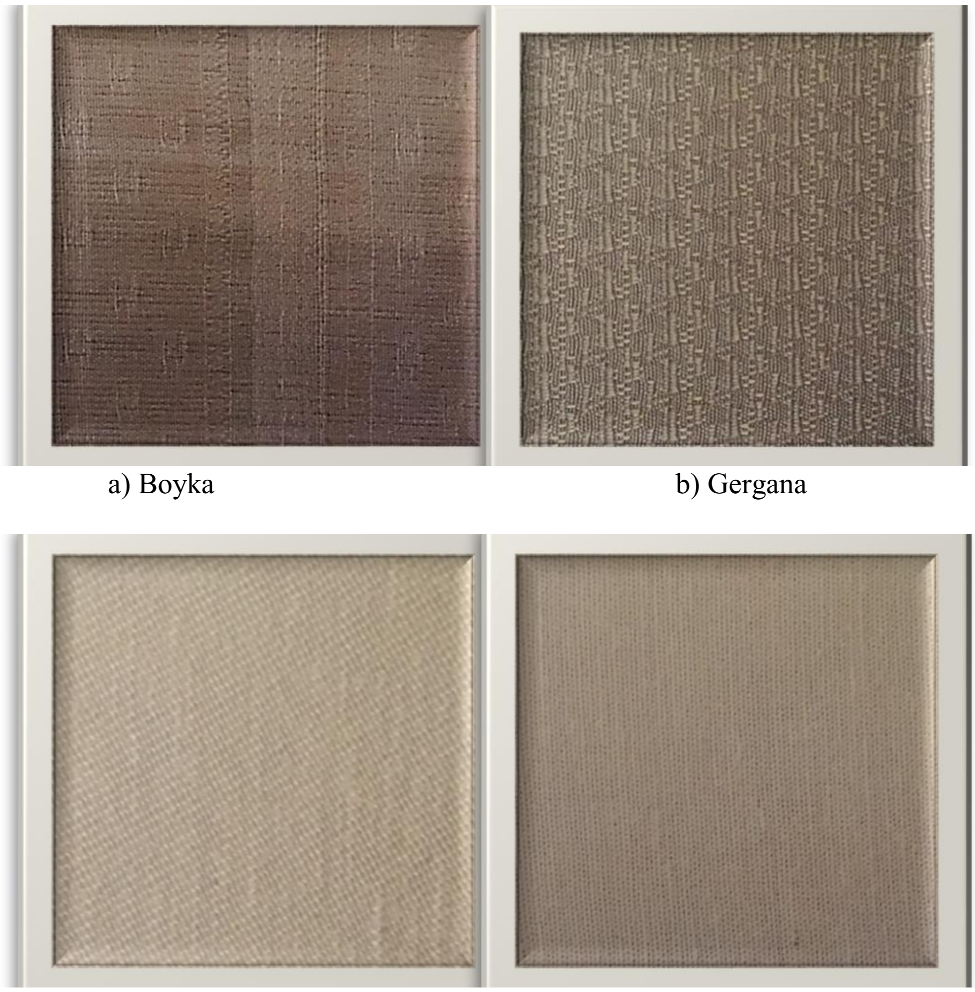

a) Boyka b) Gergana
c) Veronica d) Neda
Figure 2. Structure of examined fabrics

Table 1 Characteristics of examined fabrics made of natural silk

№	Item	Surface area, g/m^2	Linear density, tex		Density, н./dm	
			warp	weft	warp	weft
1	Boyka	76	N/A*	N/A	1660	350
2	Gergana	80	N/A	N/A	1550	175 / 175
3	Veronica	170	N/A	N/A	2060	200
4	Neda	140	N/A	N/A	980	195

Due to the high labour intensity and inaccuracy of the test, the linear densities of the fibers in the finished fabrics have not been determined.

Loss of surface mass and change in thread densities are sufficient characteristics to assess the degree of decoction and shrinkage of the fabrics.

3. Measuring devices

Friciton coefficients at rest and at sliding are obtained through work with device MXD-02 from the company Labthink, China (Fig. 1).

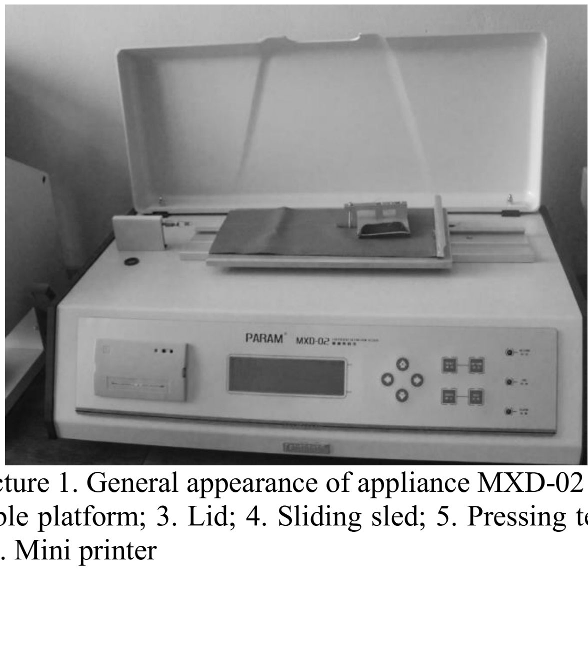
The static coefficient is determined by the force measured at the moment when the metal thread connecting force meter and sled straightens and the slide starts sliding on the platform.

The dynamic coefficient is determined by the average value of the measured friction forces. The research was conducted according to BDS EN ISO 8295: 2006. The friction was performed fabric in fabric, the block has a mass of 200 g and the sliding speed is 100 mm / min.

Placing additional weights determines the influence of the pressure force on the friction coefficients of the block. Measurements were performed at pressures of 200 g, 300 g and 400 g.

Friction is performed fabric in fabric so that two layers of the fabric (face side) are placed in different directions. One layer of the examined fabric is attached to the platform so that the direction of warp threads coincides with its direction of movement. The second layer is attached to the mobile sled in a selected direction (warp or weft).

The friction coefficient at rest μ0 is determined by the force recorded during the test. At this point, the metal thread connecting the force meter and the sled is stretched, after which it begins to slide on the platform. The appliance calculates the average value for the studied friction coefficient during sliding μ, as well as the standard deviations for μ0 and μ. The numeric values visible on the screen can be printed with the mini printer. The obtained results for μ0 and μ are detailed in table. 2.



Picture 1. General appearance of appliance MXD-02 [4]

1.Force meter; 2. Movable platform; 3. Lid; 4. Sliding sled; 5. Pressing terminal; 6. Guide rail; 7. Control panel; 8. Display; 9. Mini printer

Table 2 Friction coefficient values at rest

Item	Sled mass with additional load	Friction coefficient at rest with sliding tendency	
	g	WFS-WFS*	WFS-WeFC*
Boyka	200	0,333	0,410
	300	0,450	0,586
	400	0,582	0,759
Gergana	200	0,650	0,453
	300	0,637	0,729
	400	0,837	0,883
Veronica	200	1,148	1,190
	300	1,438	1,486
	400	1,640	1,742
Neda	200	1,054	1,167
	300	1,241	1,434
	400	1,151	1,567

* Used abbreviations in table. 2: WFS –warp face side; WeFC – weft face side. The aforementioned abbreviations are reused in the tables and graphs in the text to follow. The weight of the test textile piece mounted to the sled is neglected.

Table 3 Friction coefficient values at sliding

Item	Sled mass with additional load	Friction coefficient at sliding	
	g	WFS-WFS	WFS-WeFC
Boyka	200	0,292	0,360
	300	0,412	0,521
	400	0,530	0,674
Gergana	200	0,494	0,395
	300	0,589	0,623
	400	0,774	0,773
Veronica	200	0,904	0,928
	300	1,184	1,211
	400	1,387	1,467
Neda	200	0,991	0,993
	300	1,279	1,284
	400	1,106	1,450

It should be noted that friction coefficient values normally vary between 0 and 1; however, in some occasion the upper limit of the coefficient is greater than 1. Observing table 2 and 3, friction coefficient (both at rest and at sliding) values greater than 1 can be spotted.

As an example, friction coefficient exceeding the accepted upper limit of 1 is observed for friction at rest with sliding tendency (also known as static friction coefficient) with some metals such as aluminium in aluminium, copper in copper, gold in gold, platinum in platinum etc. Friction force is equal to the normal force when friction coefficient is equal to 1; respectively, the friction force is great to the normal force when friction coefficient is greater than 1. Looking at some existing experimental studies, friction coefficients' aggregate values for some double materials are greater than 1 [5, 6, 7], including materials such as fabrics [8, 9].

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One of the main factors found to play a significant role in the friction characteristics determination is the actual contact surface area of friction between fabrics [2]. Increased pressure causes the actual contact area to also increase due to flattening of the threads that occurs.

Experimenting with low sliding speeds (ranging from10 to 500 mm / min.) has resulted in no significant friction force differences according to studied experimental literature [11, 12]. The sliding speed used throughout this study is 100mm/min. That speed is deemed acceptable due to the above mentioned fact (friction speed influencing fabric layers relative to each other in insignificant).

The following logarithmic expression (1) determines the relationship between normal load and friction force [2, 8, 9, 10]:

$$log\left(\frac{F_i}{B}\right) = logC + n.log\left(\frac{N_i}{B}\right) \quad \text{or} \quad \frac{F_i}{B} = C.\left(\frac{N_i}{B}\right)^n \tag{1}$$

i = 1, 2,… m; B - contact area (measured in m2); C - friction parameter (measured in Pa1-n); n - friction index (without dimension); N - normal pressure (in N); F - friction force (in N); m - number of experimental observations.

For cotton and polyester /P/PE/ mixed textile materials with different ratios, experimental studies find that the logarithmic dependence approaches a linear one [4, 5, 6].

Three tests are performed for each studied fabric; an arithmetic mean value is then determined for each one. Different directions and applying different pressure is how log (Fi / B) and log (Ni / B) are determined. The pressure applied can be changed by loading the sled with an additional weight. These weights are added to the sled's own weight of 200g. The weight of the mounted to the sled piece of fabric is neglected with each test and for all studied fabrics as that weight is insignificant and does not alter the results. The room temperature and humidity conditions during all tests are kept to 22°C and 70% respectively.

Log (Fi / B) and log (Ni / B) are calculated after friction factor and friction index are determined and normal compressive forces Ni and friction forces Fi are calculated.

The below equation of linear regression is formulated:

$$y=a+x.b \tag{2}$$

$x= lg(N_i/B)$; $y= lg(F_i/B)$; $a=lgC$; $b=n$

Friction factor R (also known as "correlation friction coefficient" or "composite friction coefficient") is calculated based on the following dependence [3]. The calculation also makes use of friction index and friction parameter.

$$R = \frac{C}{n} \tag{3}$$

Table 4 presents the results for friction index for friction at rest and at sliding, friction parameter, and friction factor.

Table 4. Values of frictional characteristics at rest and sliding

Item	Direction of the fabric	Frictional characteristics at rest			Frictional characteristics at sliding		
		Index	Parameter	Factor	Index	Parameter	Factor
		n	C	R	n	C	R
		-	Pa^{1-n}	Pa^{1-n}	-	Pa^{1-n}	Pa^{1-n}
Boyka	Warp FS-Warp FS	0,570	0,352	0,617	0,438	0,010	0,017
	Warp FS -Weft FS	0,380	0,013	0,034	0,430	0,011	0,025

Gergana	Warp FS-Warp FS	0,387	0,144	0,373	0,060	0,041	0,110
	Warp FS-Weft FS	0,413	0,010	0,025	0,452	0,009	0,020
Veronica	Warp FS-Warp FS	0,555	0,154	0,277	0,336	0,081	0,292
	Warp FS -Weft FS	0,476	0,140	0,294	0,301	0,071	0,235
Neda	Warp FS-Warp FS	0,890	0,618	0,694	0,160	0,039	0,056
	Warp FS -Weft FS	0,610	0,220	0,361	0,399	0,077	0,226

4. Results analysis

This experimental study has determined that silk fabrics with higher surface mass - Veronica and Neda, display friction coefficient values at rest and in sliding greater than 1. Friction coefficient value equal to 1 means that the friction force is equal to normal force; when friction coefficient values are greater than 1 then the friction force is greater than normal force.

It was also determined that the friction factor for friction at rest is higher than that for sliding.

The friction characteristics - friction index, friction parameter and friction factor (with minor exceptions) have higher values in the direction of warp – warp.

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