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THESES OF THE Ph.D. DISSERTATION

Integrated measurement techniques of friction factors of deformable fibre products

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1. Introduction

The importance of textiles and technological fibres is increasing. Textiles have become indispensable parts of our life. It is vital that their friction properties and friction factors should be understood well in order to use the properly and to discover their further usage. Friction factors are varied depending on different raw materials, surfaces, temperatures and circumstances of handling. Their examination and applicable results of the examination might have considerable importance.

Friction is significant in every process of textile industry. At the very beginning, friction between raw fibres is essential for the yarn manufacturing; this force of friction produces solidity of yarn.

Friction is not just crucial during the processing, but influences the properties of many physical and applied characteristics, e.g. the feel of the textile, which subjective attribute is conditioned by the friction features.

It is not easy to examine friction characteristics of flexible textiles. They have been researched for a long time and the development of measuring techniques and IT offers us newer possibilities to improve our measuring devices and methods.

Many difficulties may occur while applying measuring devices and manufacturing textile products. Most of the failures are caused by friction of touching surfaces and attrition. The tribological characteristics of connected and moving surfaces are the results of very complex processes, which can be influenced by several factors.

The proper selection of material proportion and manufacturing condition can provide the favourable tribological characteristics of applied systems.

Friction characteristics not only determine the features of the end-product but the efficiency of industrial procedures, the setting of technological parameters and interaction. Friction characteristics exceedingly determine the structures of textiles.

Friction force is central to produce yarn and textiles. Friction is not only indispensable in the preparatory process, but exceedingly influences many physical and functional features of fibres and textiles, settles the option of applies technologies and possibility of procession. Technological features can be predicted based on this knowledge.

2. The Objective of this Thesis

The objective of my research is the systematization of the previous friction researches in the textile industry and analysis of their capability, and the investigation of whether the cylindrical Euler method can be improved to that one, which allows us to examine textile structures of different types and materials using the same setting and parameters provided when the friction surface can be varied.

A further aim of my thesis is to determine the correlation between friction factors of elemental fibres, filament bundles, yarns and textiles.

The following research tasks were set in order to reach our research aims:

1. Systematization and capability analysis of practically applied friction measures in textile industry regarding to the features of the examined textile structure and the capability of alteration of the friction surface.
2. Determination of whether the examining process based on the cylindrical Euler method can be improved into a universal method, which allows us to test any type of textile material on het same setting at a variable friction surface on the same device when all the parameters are the same.
3. Examination the adaptability of the cylindrical Euler method in the case of varied textile structures e.g. elemental fibres filament bunches yarn and textiles.
4. Is there any significant difference between the friction factors of textile in the dynamic and the stationary ones?
5. Examination of how does varying preload affects friction factors?

6. How does the alteration of twist number affects the friction features of fibres? Is there any relation between the number of twists and the friction factors?
7. How do repeated measures affect friction features?

3. The methods and materials used during examination

On the basis of my practical experience my hypothesis was, that during the determination of friction features of deformable fibre products some factors must be considered, which can be neglected in case of inflexible bodies.

I designed and built a measurement device with the help of my colleagues to prove my hypothesis. The device is capable of examine and determine the friction factor of elemental fibres, mono and multi filaments, threads, textiles and other deformable sheet products under the same conditions. I made it possible to adjust the range of the measurand (between 0 - 500 cN) and the specimen speed (at three steps: I. 0,4 – 4; II. 4 – 14; III. 14 - 140 [mm/min]) on the instrument, to be able to determine both friction factors (static and kinetic).

The option to change the cylinders of the device enables the investigation of custom surfaces and flexible 2D sheet products (e.g. textiles and papers), individual fibres, mono and multi filaments. The design of the device also prevents the thread from drifting out.

Results of my investigations of polyamide 6 mono and multi filament aramid mono and multi filament various textiles and papers proved, that friction factors of flexible yarn products and polymers depend on factors (preload, shape etc.), which were previously considered neglectable.

The data of the examined test bodies can be seen in tables 1, 2 and 3.

Table 1. Data of 1D test bodies

1D products	composition	Fineness [tex]	Twist number, s [1/m]	Twist Factor, αTtex	Numbers of bundle [db/köteg]
1. test body (foreyarn)	100 % cotton	366.3	100	36630	-
2. test body (monofilament)	100% poliamid-6	0.0994	0	0	-
3. test body (multifilament)	100% poliamid-6	15.9	0	0	160
4. test body (monofilament)	100% aramid	0.0994	0	0	-
5. test body (multifilament)	100% aramid	15.9	0	0	160

Table 2. Data of 2D test bodies

2D paper products	Composition	Density of surface [g/m^2]	Method of knitting	Thickness [mm]
1. test body	100 % cotton	460 g/m^2	3/1-es twill	0.859
2. test body	100% wool	365 g/m^2	3/1-es twill	0.605
3. test body	100% cotton	170 g/m^2	Plain weave	0.321
4. test body	100% cotton	73 g/m^2	Plain weave	0.16
5. test body	100% polypropylene	30 g/m^2	cling film	0.06

Table 3. Datas of Test bodies

2D paper product	Density of surface [g/m^2]	Thickness [mm]	Density of volume [g/cm^3]	Volumenity [g/cm^3]
Canon paper	82 g/m^2	101 μm	0.81 g/cm^3	1.23 cm^3/g
painted paper	77 g/m^2	70 μm	1.1 g/cm^3	0.91 cm^3/g

The combinations of tests are higher than this thesis can deal with. This new method opens the path to that friction pattern of all textile structures can be determined at the same settings and measuring parameters in the future.

Different papers and textile products has been studied. During these studies I altered the preload, repeated cycle examination and alteration of the number of twist and numbers of bundle at a particular sample. Friction factor has been determined by the aforementioned parameters. The summary of these examinations can be seen in 4th chart.

Table 4. Summary of the examinations

	Alteration of preload	Repeated cycle examination	Increasing of twist number	Increasing of bundle number
Polyamid 6 monofilament	✓	✓		
Aramid monofilament	✓	✓		
Polyamid 6 multifilament	✓	✓	✓	✓
Aramid multifilament	✓	✓	✓	✓
Cotton fibre (fore fibre)	✓	✓	✓	
Textile (various composition and knitting)	✓	✓		
Paper (unpainted 82 g/m^2)	✓	✓		
Paper (painted 77 g/m^2)	✓	✓		

4.   Theses

This thesis focuses on the determination of friction factors of flexible fibre products and the following statements can be made:

1. I designed and implemented a novel measuring instrument, which can define the friction factors (static and dynamic) of any particular fibre product e.g. elemental fibres, mono and multi filaments, yarn textiles and other paper products at same settings. This device also can examine tribological characteristics of varied material matching. Previously neglected characteristics can be taken into consideration using this new instrument.

2. I have concluded, that friction factors (static and dynamic) of polyamide 6 monofilament and polyamide 6 multifilament are dependent on the applied preload. Friction factors of polyamide 6 monofilament were depending on the applied preload linearly. Friction factors of polyamide 6 were linearly increasing in the 5 cN – 15 cN range, and were constant in the 16 cN – 50 cN range of preload. This behavior can be explained by the variation of the contact area due to the radial and tangential forces on the surface of the cylinder.
    In case of monofilaments static and dynamic friction factors behave according to the following functions:

$$\mu_{ny} = -1.6 \cdot 10^{-1} \left(\frac{F_0}{F_{0max}} \right)^2 + 2.55 \cdot 10^{-1} \left(\frac{F_0}{F_{0max}} \right) + 1.18 \cdot 10^{-1} \qquad R^2 = 0.982$$

$$\mu_{m} = -2.1 \cdot 10^{-1} \left(\frac{F_0}{F_{0max}} \right)^2 - 3.33 \cdot 10^{-1} \left(\frac{F_0}{F_{0max}} \right) + 6.4 \cdot 10^{-2} \qquad R^2 = 0.968$$

where:
μ_{ny} – static friction factor [-]
μ_{m} – dynamic friction factor [-]
F_0 – preload [N]
F_{0max} – maximum value of preload [N]

in case of multifilaments friction factors are the following:

$$\mu_{ny} = 3.86 \cdot 10^{-1} \left(\frac{F_0}{F_{0max}}\right) + 1.46 \cdot 10^{-1} \qquad\qquad R^2 = 0.96$$

$$\mu_m = 4.35 \cdot 10^{-1} \left(\frac{F_0}{F_{0max}}\right) + 1.29 \cdot 10^{-1} \qquad\qquad R^2 = 0.978$$

where:
μ_{ny} – *static friction factor [-]*
μ_m – *dynamic friction factor [-]*
F_0 – *preload [N]*
F_{0max} – *maximum value of preload [N]*

3. I determined, that that friction factors (static and dynamic) of polyamide 6 monofilament and polyamide 6 multifilament are decreasing linearly with the number of repeated measurements. The rate of decrease is the function of preload. The contact surface increases together with the applied preload, the repetitions cause the improving mutual smoothing of contact surfaces, surface roughness decreases, thus friction factors also decrease.

In the case of monofilaments static friction factors can be determined by the following functions:

0.5 cN preload:
$$\mu_{ny} = -2 \cdot 10^{-3} n + 1.67 \cdot 10^{-1} \qquad\qquad R^2 = 0.89$$

1 cN preload:
$$\mu_{ny} = -1 \cdot 10^{-3} n + 2.1 \cdot 10^{-1} \qquad\qquad R^2 = 0.889$$

1.5 cN preload:
$$\mu_{ny} = -1 \cdot 10^{-3} n + 2.09 \cdot 10^{-1} \qquad\qquad R^2 = 0.859$$

2 cN preload:
$$\mu_{ny} = -1 \cdot 10^{-5} n + 2.24 \cdot 10^{-1} \qquad\qquad R^2 = 0.655$$

where:
μ_{ny} – *static friction factor [-]*
n – *number of repetitions [-]*

dynamic friction factors can be determined by the following functions:

0.5 cN preload:
$$\mu_m = -2 \cdot 10^{-3} n + 1.35 \cdot 10^{-1} \qquad\qquad R^2 = 0.85$$

1 cN preload:
$$\mu_m = -1 \cdot 10^{-3} n + 1.78 \cdot 10^{-1} \qquad\qquad R^2 = 0.9$$

1.5 cN preload:
$$\mu_m = -1 \cdot 10^{-3} n + 1.87 \cdot 10^{-1} \qquad\qquad R^2 = 0.694$$

2 cN preload:
$$\mu_m = 1 \cdot 10^{-5} n + 2.01 \cdot 10^{-1} \qquad\qquad R^2 = 0.925$$

where:
μ_m – *dynamic friction factor* [-]
n – *number of repetitions* [-]

In case of multifilaments static friction factors can be determined by the following functions:

5 cN preload:
$$\mu_{ny} = -2 \cdot 10^{-3} n + 2.08 \cdot 10^{-1} \qquad\qquad R^2 = 0.855$$

15 cN preload:
$$\mu_{ny} = -1 \cdot 10^{-3} n + 2.36 \cdot 10^{-1} \qquad\qquad R^2 = 0.855$$

25 cN preload:
$$\mu_{ny} = -1 \cdot 10^{-3} n + 2.38 \cdot 10^{-1} \qquad\qquad R^2 = 0.733$$

35 cN preload:
$$\mu_{ny} = -1 \cdot 10^{-3} n + 2.65 \cdot 10^{-1} \qquad\qquad R^2 = 0.87$$

where:
μ_{ny} – *static friction factor* [-]
n – *number of repetitions* [-]

dynamic friction factors can be determined by the following functions:

5 cN preload:
$$\mu_m = -1 \cdot 10^{-3} n + 1.98 \cdot 10^{-1} \qquad\qquad R^2 = 0.82$$

15 cN preload:
$$\mu_m = -1 \cdot 10^{-3} n + 2.34 \cdot 10^{-1} \qquad\qquad R^2 = 0.861$$

25 cN preload:
$$\mu_m = -1 \cdot 10^{-3} n + 2.35 \cdot 10^{-1} \qquad\qquad R^2 = 0.791$$

35 cN preload:
$$\mu_m = -1 \cdot 10^{-3} n + 2.65 \cdot 10^{-1} \qquad\qquad R^2 = 0.905$$

where:
μ_m – *dynamic friction factor* [-]
n – *number of repetitions* [-]

4. I concluded, that the static and dynamic friction factors of the multiple bunch, composed of more (1-5) multifilaments without twist of polyamide 6 are dependent on the number of bunches.

The deformation caused by the preload is the result of the deformation of the bunch and the items that make up the bunch. The increase of the linear density at constant load causes the friction factors to increase linearly first, than becomes constant. The static and dynamic friction factors can be defined as follows:

$$\mu_{ny} = 1.3 \cdot 10^{-2} k + 2.44 \cdot 10^{-1} \qquad\qquad R^2 = 0.869$$

$$\mu_m = 1 \cdot 10^{-2} k + 2.46 \cdot 10^{-1} \qquad\qquad R^2 = 0.807$$

ahol:

μ_{ny} – *static friction factor* [-]

μ_m – *dynamic friction factor* [-]

k – *number of bundle* [-]

5. I concluded, that the static and dynamic friction factors of polyamide 6 multifilament increases with the number of twists and their values converge to each other. The twist decreases the deformation of the multifilament on the frictional surface. Increasing the number of twist makes the surface of the thread structure homogenous, decreasing the deformation of the bunch and the contact surface. The static and dynamic friction factors can be defined as follows:

$$\mu_{ny} = -1.7 \cdot 10^{-2} \left(\frac{S_0}{S_{0max}} \right) + 2.47 \cdot 10^{-1} \qquad\qquad R^2 = 0.792$$

$$\mu_m = -1.4 \cdot 10^{-2} \left(\frac{S_0}{S_{0max}} \right) + 2.41 \cdot 10^{-1} \qquad\qquad R^2 = 0.93$$

ahol:

μ_{ny} – *static friction factor* [-]

μ_m – *dynamic friction factor* [-]

S_0 – *number of twists* [1/m]

S_{0max} – *number of twists* [1/m]

5. Important Publications Related to the Research

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8. **Oroszlány G.,** - Koltai L.: Textilanyagból készült csomagolóeszközök Textile materials for packaging Magyar Textiltechnika - a Textilipari Műszaki és Tudományos Egyesület, mint az MTESZ tagegyesületének lapja LXII. évf./III.sz. 2010/3 szám pp.: 101-104 (3 old.)

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