DETERMINATION OF THE FRICTION CHARACTERISTICS OF PAPERS THEORETICAL FOUNDATIONS, DEVELOPMENTS IN MEASUREMENT ENGINEERING

Gabriella Oroszlány, László Koltai
Rejtő Sándor Faculty of Light Industry and Environmental Engineering,
Óbuda University, Budapest

Abstract:

Varying with the different surfaces, the circumstances of use and temperature values, the friction factors of base materials show differing values. The examination of such circumstances and reliance on the obtained results have outstanding significance in the selection and further processing of flexible sheet products, such as papers and cardboards.

During the operation of equipment and devices in the paper and printing industry, as well as in the course of manufacturing paper products, a number of technical problems can potentially occur, because friction properties do not only determine the characteristics of the final product, but also the efficiency of industrial operations, the setting of technological parameters and their interrelations. The printability of papers, the way how they can be run in printing presses, the contact properties of the toner and printing media or adhesive binding are all obviously correlated with the unevenness of sheet surfaces. In industrial practices, this property of materials is described with the use of the so-called (Bekk's) smoothness grade. The determination of the friction factor yields usable values in relation to the surface structure, because the nature of this measurement and the actual industrial stress on papers are very similar to each other.

To establish one new measurement method, we have assessed and analyzed the technical designs and measurement capabilities of the existing techniques. We have wanted to create a solution that is suitable for the determination of the friction properties on "any" surface under identical circumstances. The basis of the experimental equipment has been an Fm-27 electronic tensile strength tester for filaments.

Keywords: *friction factors, surface, paper, Euler's method*

1. INTRODUCTION

The friction factor of different materials and surfaces depends on the temperature and other numerous conditions of usage. The investigation of the interaction of such parameters and its results can have practical benefit regarding the processing of flexible sheet products, such as papers and cardboards. In the paper and printing industry, especially during paper product manufacturing material friction properties may be different from that of the final product, which makes the prediction of such properties complicated. Friction properties of sheet products may be changed by printing, finishing, and other processing stages.

The friction factor is an empirical measure depending on the material quality of contacting surfaces, a ratio without actual dimensions. Its value can be determined in experiments; there are several solutions and methods for the determination of the actual value.

For any given pair of surfaces, the friction coefficient (μ) can have two kinds of values as depending on the fact whether the surfaces are moving (dynamic friction coefficient), or not moving (static friction coefficient) in relation to each other. Usually, the static friction coefficient is larger than the sliding or dynamic coefficient.

It is not easy to determine the friction of papers, yet it is essential in technical life to be ware of such information. The task is a hard one with respect to flexibility, because these materials can bend or even twist to any direction of the given space.

Methods for the determination of friction or the friction factor: on the basis of Coulomb's law or Euler's law. There have been several examination methods invented for the determination of the friction properties of flexible structures. A particular characteristic of these examination methods that the examination results of identical materials can frequently and considerably differ from each other. The underlying reason is that with the use of the various methods the setting parameters of the equipment and the surfaces sliding on the examined samples may be different from each other, and therefore the obtained results are hardly or actually non-comparable with each other. Consequently, the results are always specific to the given method, and therefore when they are published and evaluated the applied measurement method and surface should also be designated. [1] The foregoing details also suggest that the applicability of the individual methods is limited, and thus it is time to establish a measurement method that rectifies all these problems.

To establish one new measurement method, we have assessed and analyzed the technical designs and measurement capabilities of the existing techniques. We have wanted to create a solution that is suitable for the determination of the friction properties on "any" surface under identical circumstances.[2]

2. EXPERIMENTAL

With the selection of the basic machine, we have strived for choosing such a device whose measurement range is in line with the expected results, still it may be increased or decreased freely within certain limits.

The experimental equipment has been primarily designed for the determination of the friction properties of flexible structures, and it has been to be suitable for the definition of the friction properties of papers, foils, textile structures, threads and filaments.

The basis of the experimental equipment has been an Fm-27 electronic tensile strength tester for filaments. The device is a tensile strength tester of vertical arrangement, feed-rack design tension tester and electromechanical control. During the test, the upper clamping structure makes insignificant movement, and therefore the device is a machine with a permanent rate of stretch. The speed can be varied within broad limits, in 3 steps, but continuously, and a standard breaking time may as well be set.

Figure 1. Fm-27 type electronic tensile strength tester for filaments

The tensile force is transformed into an electronic measuring sign by an inductive measuring transformer. Changes in length are measured by a photoelectric measuring transformer detecting the rate of turn of the stretching reel. The values for the friction force can be read from the same graph during the evaluation.

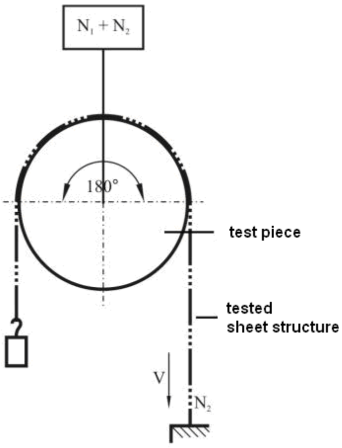

Figure 2. Theoretic drawing of the measuring device

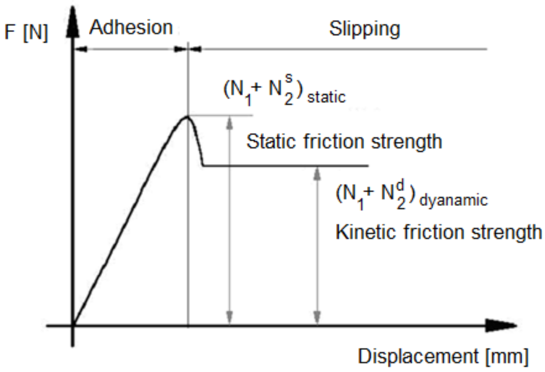

Figure 3. Test graph

Presented from a side view above, the cylindrical test piece of the equipment can be replaced by a piece of any other base material, or covered with paper. The sheet structure to be tested has to be applied to the test piece. One end of the test strip has to be nipped in clamp N_2, while the other end has to be pre-loaded with weight N_1. A precondition of the test: $N_1 < N_2$.

When the test is launch, N_2 clamping structure will start to move towards the designated direction at "V" speed. When during the test the value of adhesive friction is reach and exceeded, the test strip will slip on the test piece, and start to move to the direction of the "V" speed.

The graph drawn on the basis of the test exposes accurate information in relation to the size of both the adhesive and sliding friction.

The value of the friction factor can be determined with the use of the following equation.

$$N_2 = N_1 \cdot e^{\mu \cdot \alpha} \quad \text{(Eq. 1)}$$

wherein:

N_2 – friction force [N],

N_1 – tensile force [N],

α – turning angle [rad],

μ - friction factor, proportionality coefficient [-].

A huge advantage of this test solution is that at the time of the examination of the test strip one graph is sufficient for the determination of both the static and dynamic friction coefficient.

In comparison with the theoretical arrangement described above, further alterations have been made to the basic equipment. The single-cylinder design with the 360° turnaround angle did not allow the examination of the friction of "broad" paper samples. As depending on the width, the 360° turnaround angle of the tested sample caused twisting, and thus modified the original arrangement. Another problem arose from the contacting edges of the samples, which made the accuracy of the measurements uncertain. [3]

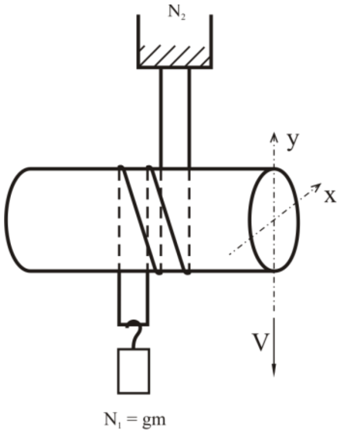

Figure 4. Examination arrangement of the test piece with one cylinder

Still an additional problem was caused by measurement on paper-covered surfaces, because to some extent overlaps were created when paper was applied to the test cylinder. These overlaps hindered the even application of the sample and accurate measurement.

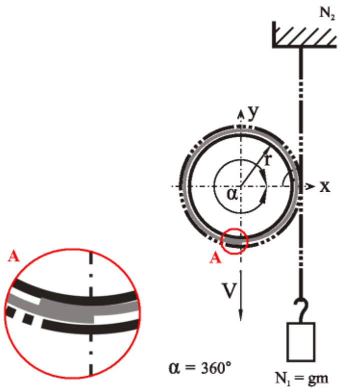

Figure 5. Test cylinder covered with paper, overlap

These problems have been eliminated with the suspension of a second cylinder. This solution consisting of two cylinders allows the paper sample to become laid without any twist for the test. The width of the sample can be increased up to the width of the test cylinder (max. 100 mm). The new two-cylinder solution also rectifies the problem concerning the covering of the cylinders, because the 180° turnaround angle on each cylinder leaves sufficient space for the overlapping of the “covering material”.

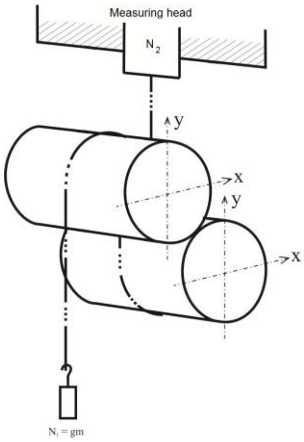

Figure 6. The two-cylinder setup

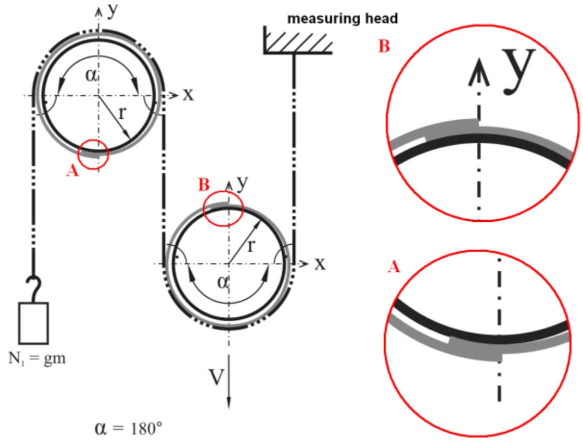

Figure 7. Two-cylinder test arrangement covered with paper

3. RESULTS

3.1 Registration and digitalization of the signal at the measuring head test point

The electric signal displayed on the measuring head of the device in proportion of the tensile force is given by an audio-frequency measuring bridge. In the case of the basic equipment, this signal can be read from the digital display after appropriate conversion, yet this value will be equal to the peak value from time to time. In design work, it is not the peak value that is needed, but the momentary force value that belongs to each displacement unit. Therefore, the signals continuously arriving from the "test point" identified in the block diagram of the device are registered, eliminating the unnecessary elements of the original control of the equipment. After the startup of the measuring cycle of the appropriately prepared and registered sample, the conversion of the analogous signs into digital signals is commenced. This task is performed by a digital signal converter that also forwards the signal to a PC.

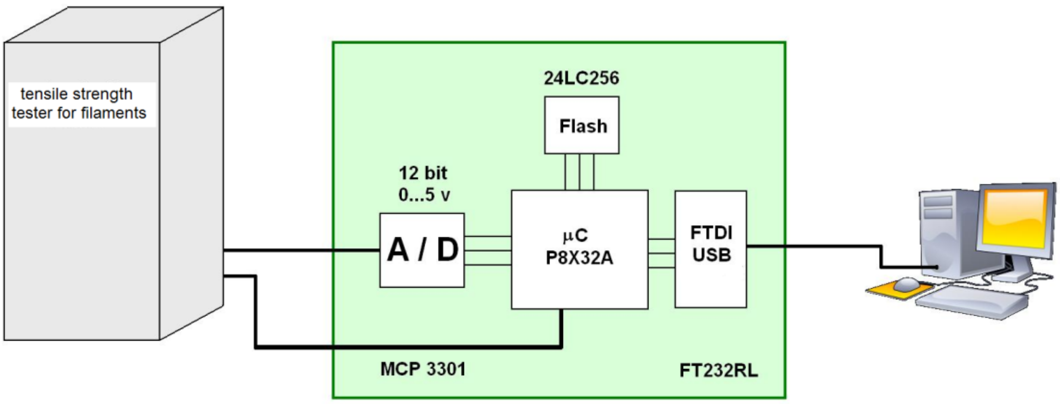

Figure 8. Structure of the digitalizing interfacing panel of the tester

A peripheral interfacing program "receives" the signals, and presents their graphic forms on the graphic display interface. Upon the completion of the measuring cycle, the conversion and forwarding of signals are discontinued, and the measuring device is reset to the initial position.

3.2 Testing the novel measurement setup

We tested the novel measurement setup using sheets of office copy and coated paper. Sample data are shown in tables 1-2.

Table 1. Dimensional properties of the test sheets

	Copy paper	Coated paper
Grammage	82 g/m^2	77 g/m^2
Caliper	101 microns	70 microns
Density	0.81 g/cm^3	1.1 g/cm^3

Table 2. Measured physical properties of the test sheets

	Copy paper		Coated paper	
	MD	CMD	MD	CMD
Tensile strength	57.66 Nm/g	19.55 Nm/g	27.18 Nm/g	18.85 Nm/g
Relative stretch	2.22 %	3 %	2.05 %	2.2 %
Tear strength	374.74 N	486.58 N	353.16 N	294.30 N
Tear index	0.43 mNm^2/g	0.62 mNm^2/g	0.46 mNm^2/g	0.39 mNm^2/g

We investigated the behavior of the friction properties of coated and uncoated papers. Friction coefficient were determined by gradually increasing the load weight (figure 9-10). The measured data were processed and statistically evaluated according to the elaborated novel method with textile specimen. [3]

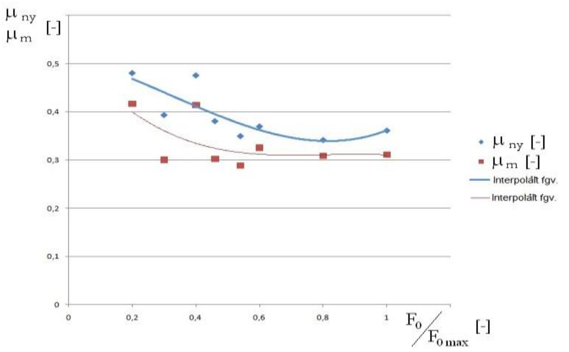

Figure 9. Static and dynamic friction coefficients plotted as a function of load weight in the case of Canon copy paper

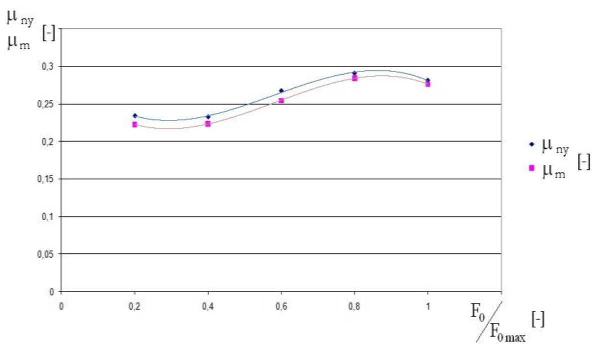

Figure 10. Static and dynamic friction coefficients plotted as a function of load weight in the case of coated paper

The effect of repeated measurement cycles was also examined. The test sample was measured 20 times consecutively, results of the measurement are plotted on figure 11.

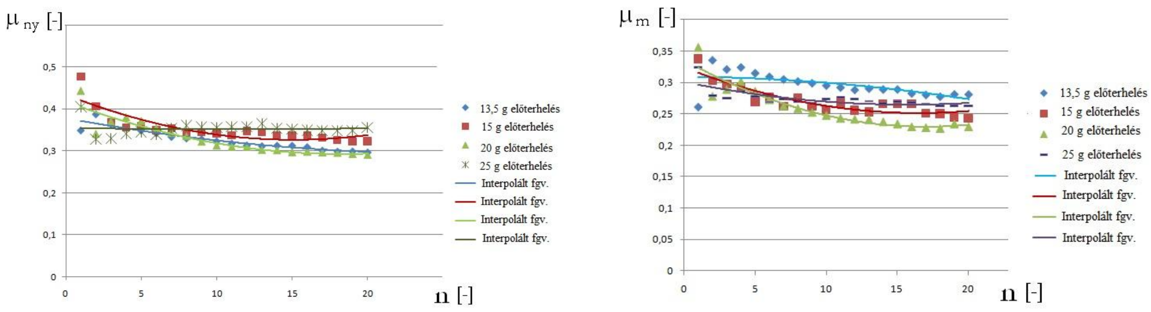

Figure 11. Test results of Canon copy paper (80g/m2); static (left) and dynamic (right) friction coefficients in repeated cycles

The repeated cycle measurements produced static and dynamic friction coefficients that were not constant, but dependent on the number of cycles and the applied load weight.

4. CONCLUSIONS

We studied the friction properties of flexible sheet products (papers, foils). A novel measurement setup and equipment was applied, this system was originally developed for the investigation of textile structures. The principles and technical methods were adapted for the measurement of paper sheets. We examined the applicability of the two-cylinder Euler method, and the effect of the load weight on the friction coefficient values. We found that static and dynamic friction coefficients were dependent on the load weight and the number of measurement cycles.

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Corresponding address:
László KOLTAI
Institute of Media Technology
Rejtő Sándor Faculty of Light Industry and Environmental Protecting Engineering
Óbuda University
Doberdó út 6.
1034, Budapest
Hungary
Phone: 36-1-666-5981, e-mail: koltai.laszlo@rkk.uni-obuda.hu