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# Development of an Innovative Attachment Determining Friction Parameters for Quality Assessment in Sustainable Processing

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**Abstract:** New trends forcing the attractiveness of products in sustainable processing make it necessary to search for innovative methods of measuring their quality. For various biological materials, their physical properties, such as friction parameters in addition to their texture, are very important. Friction determines the course of many technological operations, e.g., transport, cleaning, sorting, fractionation, storage, and dosing of materials. An innovative friction adapter was developed for biological raw materials and tested on samples of self-produced soap. A 3D printing method for the production of this attachment was used. The soap sample loads were 100, 200, and 500 g, and the measurements of frictional resistance were carried out in contact with dry or water moistened synthetic leather, in comparison with sandpaper. For all tested variants (surfaces × loads), the initial friction of soap ranged from 0.853 N to 5.316 N, dynamic friction from 0.123 N to 3.542 N. The static and dynamic friction coefficients ranged from 0.019 to 0.151 and 0.006 to 0.131, respectively. The developed adapter for testing the friction coefficient ensures easy and quick assembly of the analyzed sample, its quick exchange and stable operation in both measurement directions, i.e., pushing and pulling the sample, as well as the possibility of using a lower applied load.

**Keywords:** quality in sustainable development; static friction; dynamic friction; soap; texture; physical properties

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**Citation:** Mazur, J.; Różyło, R.; Wójcik, M.; Panasiewicz, M.; Zawiślak, K.; Sobczak, P. Development of an Innovative Attachment Determining Friction Parameters for Quality Assessment in Sustainable Processing. *Sustainability* **2022**, *14*, 12986. https://doi.org/10.3390/su142012986

Academic Editor: Antonio Caggiano

Received: 31 August 2022
Accepted: 7 October 2022
Published: 11 October 2022



## 1. Introduction

The knowledge of the physical properties of biological materials is essential when designing machines and devices for harvesting, transport, storage, and processing. It is also necessary for modelling phenomena in individual technological operations and entire processes [1,2].

Determining the physical properties of biological materials is not an easy matter and often requires a certain number of repetitions due to their specific nature, e.g., texture of the external surface, various shapes and dimensions, or changing properties under the influence of changing environmental conditions, e.g., humidity, temperature, pressure, etc. [3,4].

One of the most important physical properties of biological materials is friction. Friction determines the course of numerous technological operations, in particular, such as transport, cleaning, sorting, fractionation, storage, and dosing of materials [5–7].

The basic criterion for the distinguishing types of friction is the type (occurrence) of the movement. At the moment of the beginning of the relative motion of the friction bodies, the friction is defined as static (at rest). On the other hand, if the bodies are moving in relation to each other or the surrounding medium, then we are dealing with kinetic (movement) friction.

Kinetic friction is related to the force necessary to overcome the resistance between the moving bodies in order to maintain motion at a certain constant speed [8–10].

In the case of static friction, the frictional force counteracting the relative motion is less than or equal to the forces (force components) causing the motion. Its direction coincides with the trajectory of relative displacement, but its direction is opposite to the displacement line.

The type and condition of the friction surfaces have the most important influence on the maximum value of the static friction force [11].

In addition to the above-mentioned types of friction, external (dry) and internal friction are distinguished due to the place where this phenomenon occurs. The first of these two types of friction occurs during direct surface contact of solids. It is caused by the action of the normal force (reaction) that presses these bodies and the tangential force (reaction) that displaces them in relation to each other [12].

The friction on the contact surface of two or more different materials is a particularly important matter in the processes of processing, transport, and mutual contact of bodies [13–16].

For practical reasons, it is important to determine the values of the static friction coefficients for surfaces made of various construction materials, e.g., steel [17,18], wood, PVC [19], rubber [11], etc. [20].

The coefficients of static friction of wheat kernels against a galvanized metal sheet, plywood and plexiglass were determined by Markowski et al. [19]. Kaliniewicz et al. [18] determined the coefficient of static friction against the steel surface for various cereals (wheat, rye, barley, oats, and triticale) and for different seed orientation. They noted that the coefficient of static friction was correlated mainly with the seed thickness. Zhang et al. [17] carried out parametric studies to reveal and explain the influence of the dimensionless coating thickness and the material properties of the coating and surface on the static friction coefficient.

Information on the impact of the type of construction material and the roughness of its working surface on the “amount” of friction of biological material particles mainly applies to materials used in the construction of devices (working elements) and facilities for their storage. The research results in this area mainly concern such materials as: steel, wood [2,18], rubber [18], PVC and aluminum [21,22].

The authors of the above-mentioned papers provide average values of the friction coefficients and/or their variation ranges for specific friction pairs (surface material-seed species). In practice, the value of external friction for single particles of various materials (e.g., loose) is expressed by the static friction coefficient (determining the beginning of the particle’s movement on the given surface) and the kinetic friction coefficient (defined for the particle already in motion). Both the beginning of the movement and the movement of the particle on the surface may be of various nature - the particle may slide, roll or move in a complex motion [2,23,24].

The most important factors having a decisive influence on the friction of plant materials include normal pressure, type of construction material, the surface roughness of friction materials, species (variety) of plant material, plant material moisture, and orientation of the tested biological material in relation to their direction of movement [25,26]. The impact of steel plate roughness on the frictional properties of cereal kernels was tested by Kaliniewicz et al. [25]. The studies were performed on the kernels of wheat, rye, barley, oats, and triticale. The external friction angle of flat seed units was determined on nine steel friction plates with different roughness. The authors concluded that friction plates made of ST3S steel have the lowest surface roughness thus minimizing energy consumption in grain processing. Effects of the friction plate hardness and surface orientation on the frictional properties of cereal grains were tested in other research [26]. The average angle of static friction was affected mainly by the surface orientation of the friction plate that came into contact with cereal kernels. The angle of static friction was higher when the friction plate had perpendicular rather than parallel surface orientation. The plate hardness had a smaller impact on the frictional properties of kernels.

Due to the above, for the measurement of the static and dynamic friction coefficient, various devices have, so far, been developed based on three measurement methods called the pulling force, the tilting plate and the rotating disc [10]. For example, the commercially available texture analyzer TA.XT plus (Stable Micro Systems, London, UK) with EXPONENT software version 6.1.5.0 (Godalming, UK), has, in addition to the texture measurement adapters, an adapter that enables the measurement of kinetic friction. This solution works well for testing various types of creams and similar substances [27]. Unfortunately, it is not suitable for testing the dynamic friction of solids on various surfaces and this is an important factor in testing properties of materials such as soaps, etc.

Due to the above, the aim of the work was to develop and test an innovative adapter for measuring the friction coefficient of soap.

## 2. Materials and Methods

### *2.1. Preparation of Experimental Materials*

The research material used in the measurements was soap made of a transparent soap base (Forbury Super Clear SLS Free, Reading, UK). The production technology consisted of dissolving the soap base in a water bath at a temperature of approximately 67 °C. The water temperature was controlled with a thermometer so that it did not exceed 70 °C, as the base above this temperature loses its properties. Subsequently, the molten soap base was poured into a rectangular mold with holes of 26 mm in diameter, 5 g each. The soaps were allowed to set at room temperature for 50 min. The soaps were made in 10 replications.

### *2.2. Development of an Attachment for Determining the Friction Coefficient*

Due to the necessity to adapt the TA XT plus texture analyzer manufactured by Stable Micro Systems (London, UK), original additional instrumentation for the horizontal friction adapter to this texture analyzer was developed and registered with the Polish Patent Office under number W.130067. This solution can also be used in other types of similar texture analyzers.

The principle of operation of the attachment for determining kinetic friction parameters, which is coupled with the analyzer, equipped with a base and a movable arm with a load cell, consists in the fact that it has a sample pusher mounting. On one side it is screwed to a movable arm and equipped with brackets, between which there is a movable rod. A sample pusher is screwed to the other end. The sample pusher consists of a mounting part and a holder. The fastening part has vertical channels at the top and the holder has pins that are nested in the channels. In the holder, there is a seat, which has a sample recess on the underside and a recess for a weight on the top.

Additionally, the attachment has at least one reduction ring located in the recess for the weight. The measurement of friction parameters is carried out by analyzing the sample movement in relation to the base and recording the force necessary to move the sample (overcoming the dynamic friction resistance) by the texture analyzer. The presented device allows for the precise setting of the sample while moving in relation to the analyzed surface. The stable location of the sample in relation to the movable measuring arm is ensured by the sample and weight seat. The seat also allows the application of additional pressure force by loading the analyzed sample with a known weight placed above the sample in the upper cavity of the socket. This solution ensures the stability of the sample's movement relative to the base and the ease of changing the sample to another one. The adapter enables stable operation in both measuring directions (pushing the sample and pulling the sample) and the possibility of using a different load. Friction analyzes can be performed on various surfaces that can be mounted on the base, and, additionally, with the application of various lubricants (e.g., surface wetting or coating with greases). The general view of the proposed solution is shown in Figure 1.

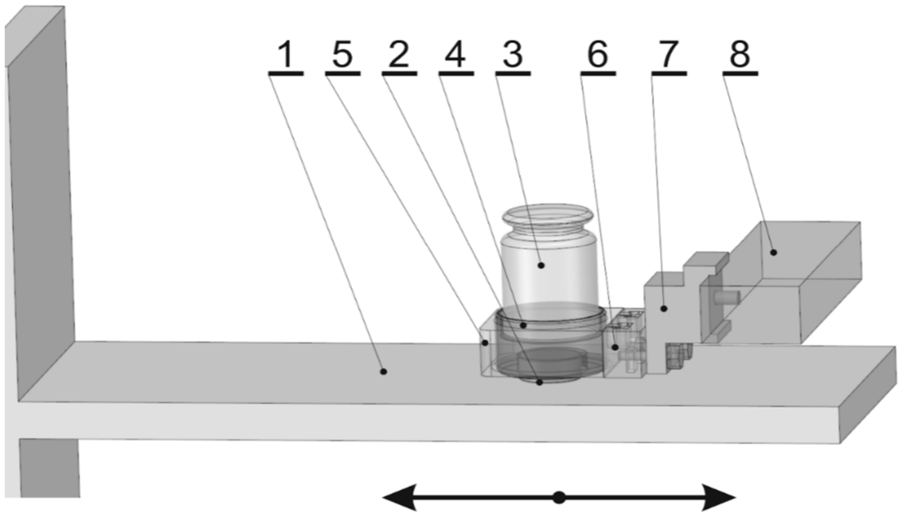


**Figure 1.** View of the attachment with the instrumentation for measuring kinematic friction: 1—attachment base, 2—analyzed sample, 3—weight, 4—sample and weight seat, 5—disassemblable sample pushers, 6—disassemblable sample pusher-fixing part, 7—pusher mounting, 8—movable texture analyzer arm with a load cell.

Figure 1 shows the mounting of the pusher mounting part (6) with the pusher mounting (7), which is twisted and attached to the movable arm of the texture analyzer with a strain gauge recording the forces occurring when moving such a complex set against the test surface that are the result of the friction of the analyzed sample against the surface.

If other texture analyzers are used, a modified pusher mounting (7) can be used. Measurement of friction parameters is carried out by moving the analyzed sample (2) relative to the base (1) and recording the force necessary to move the sample (overcoming dynamic friction resistance) by the texture analyzer. The presented device allows for the precise setting of the sample while moving in relation to the analyzed surface. A steady setting of the sample in relation to the moving measuring arm is ensured by the lower seat of the sample and the weight (4). The seat also enables the application of additional pressure force by placing a known weight on top of the sample, in the upper seat of this pusher. This solution ensures the stability of the sample movement in relation to the base (1) and the easy exchange of a sample to another one. The mechanism of inserting the sample (1) in the socket (3) and applying additional pressure by placing a known weight (2) is shown in Figure 2.

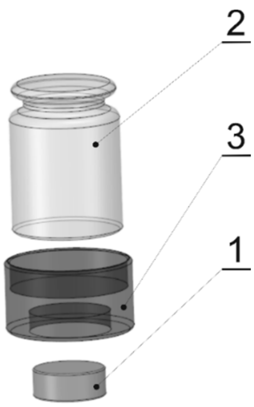


**Figure 2.** View of the sample with a socket and a weight: 1—analyzed sample, 2—weight, 3—socket.

Figure 3 shows the list of individual elements of the pusher and elements of the sample seat. The seat (3) with the sample (1) and potential additional weight (2). This set is placed in the pusher (4), which is inserted into the second part of the pusher (5).

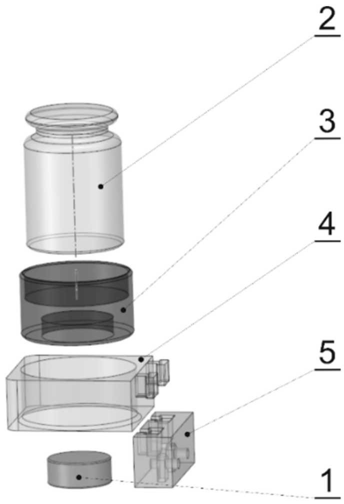


**Figure 3.** View of the disassemblable sample pusher: 1—analyzed sample, 2—weight, 3—sample and weight seat, 4—disassemblable sample pusher, 5—disassemblable sample pusher–fixing part.

If it is necessary to use weights with a lower mass, reduction rings (2) are used in the proposed set, with the internal diameter adjusted to the size of the weight (Figure 4).

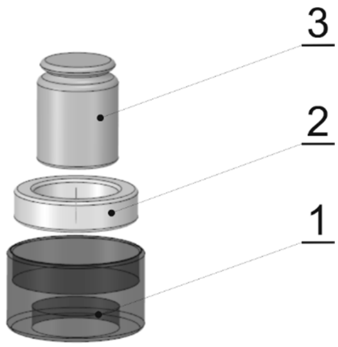


**Figure 4.** View of the disassemblable sample pusher: 1—sample and weight seat, 2—reduction ring, 3—weight.

### *2.3. 3D Printing Method for the Production of the Attachment Determining the Friction Coefficient*

Individual elements of the adapter for determining the friction coefficient were developed using the DesignSpark Mechanical 5.0 program (Sidney, Australia). In this way, the prepared elements were cut into layers in order to prepare for 3D printing using the Ultimaker Cura program. 3D printing of individual elements was carried out using ABS plastic (Fiberlogy, Brzezie, Poland) (Ø = 1.75 mm with good mechanical properties). The Creality Ender-3 Pro (Beijing, China) 3D printer was used for their production. The elements were printed with the extrusion head temperature of 250 °C and the speed of 30 mm·s$^{-1}$, and the sample was 100% filled with material. The temperature of the bed on which the printout was made was 100 °C. Printing took place in a thermostatic chamber at a temperature of 60 °C.

### *2.4. The Method of Assessing the Suitability of the Attachment Determining the Friction Coefficient*

The assessment of the usefulness of the developed attachment was carried out with the use of cylindrical soap samples with the diameter of 26 mm (±0.1 mm) and the height of 12 mm (±1 mm) and the weight of 5 g (±0.5 g). The sample loads were 100, 200 and 500 g. The total sample load was equal to the sum of the weight of the sinker and the weight of the socket, thus 105 g, 205 g and 505 g.

Measurements of frictional resistance were carried out in contact with synthetic leather (at a relative air humidity of 40 ± 5%) and when the surface was moistened with distilled water (1 $cm^3$ of water spread on the analyzed surface 10 s before the test). Additionally, a comparative test was also performed against dry 320 grit sandpaper. Simulations of extreme cases of using soap, i.e., an attempt to soap on dry skin, an attempt to soap with water, and an attempt to soap dirty, rough hands without water were used.

The measurements were carried out based on the procedure developed by Stable Micro Systems: measuring bi-directional friction properties of materials using the Horizontal Friction System. The measurement method was developed in accordance with the modified ASTM Standard Method D1894 [28].

The measurements of initial friction (Stiction), dynamic friction (Friction), work completed by friction during the dynamic friction, static friction coefficient Us, dynamic friction coefficient Uf, and dynamic friction linear sliding distance were carried out.

The static friction (Stiction) coefficient Us was determined from the following relationship:

$$\text{Us} = \frac{\text{Stiction}}{\text{Pressure of the sample}} \tag{1}$$

The dynamic coefficient of friction Uf was determined from the following relationship:

$$\text{Uf} = \frac{\text{Friction}}{\text{Pressure of the sample}} \tag{2}$$

The test speed of the sample during the friction test in both directions was 2.5 $mm \cdot s^{-1}$, the travel distance of the measuring platform was 100 mm, the initial shift before starting dynamic friction measurements was 1 mm.

*2.5. Statistical Analysis*

The tests were carried out in 5 repetitions. The obtained results were analyzed statistically. Basic statistics were calculated. Homogeneous groups were determined using the HSD Tukey test and the confidence intervals of the parameters assessed were used at the level of 95%.

## 3. Results

The results of the friction parameters for the soap obtained using the developed adapter against a variety of surfaces including leather, water moistened leather, and sandpaper are shown in the graphs below (Figures 5–10). Moreover, the tables (Tables 1–6) show the maximum and minimum values for these friction parameters. As mentioned above, the attachment has been developed in such a way that it is possible to use interchangeable base surfaces and to moisten the surface or coat with greasing agents. This solution allows for wide and universal use of this adapter for measuring friction. In addition, the friction measurements were carried out at various applied loads equal to 100, 200 and 500 g. It should be noted that the seat is designed in such a way that it is possible to use different weights of known mass, thus applying additional pressure force. In line with the methodological assumptions, the tests also confirmed that this solution ensures the stability of the sample's movement relative to the base and ease of interchanging the samples.

The obtained measurements of the initial friction (Stiction) (Figure 5) of the soaps showed significant differences in friction between the soap and the base consisting of the leather moistened with water (leather + water) at each tested pressure (9.33 kPa; 3.79 kPa and 1.94 kPa).

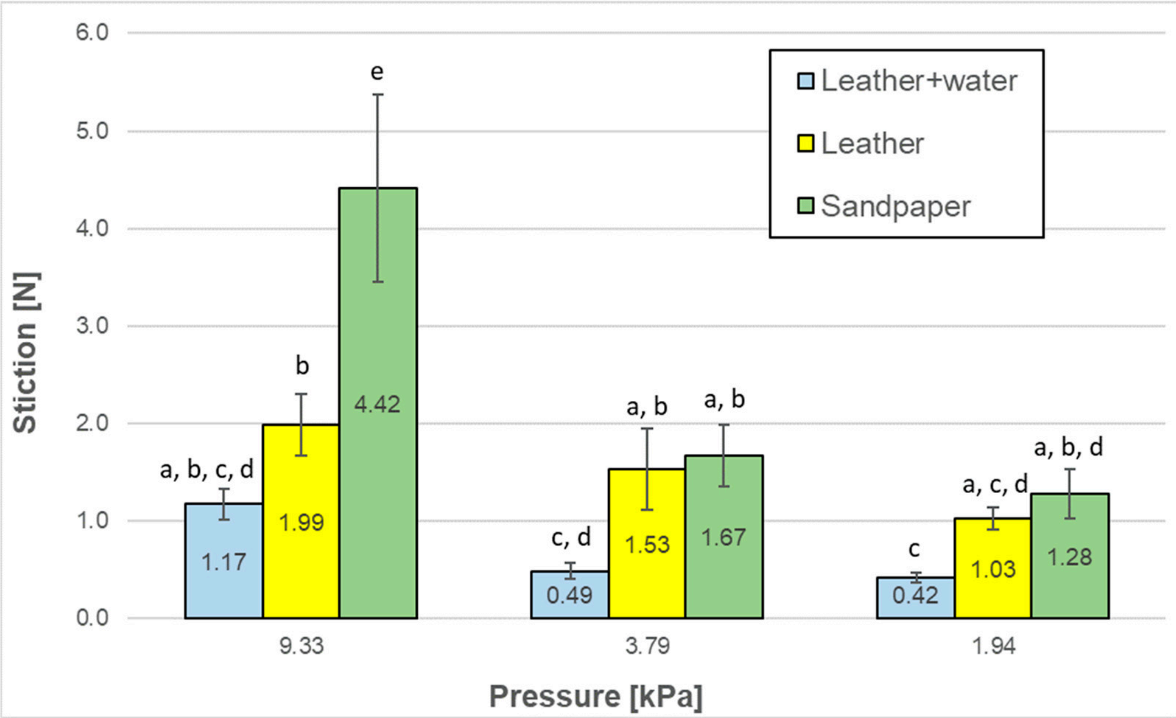


**Figure 5.** Initial friction (stiction) of the analyzed soap samples. a–e the same letters indicate belonging to one homogeneous group (α = 0.05).

For the soap tested on the dry leather, there were no significant differences between the highest and medium pressure (9.33 kPa and 3.79 kPa) and medium and low pressure (3.79 kPa and 1.94 kPa).

The static friction of the soap with the highest load differed significantly from this parameter for the medium and low loads of the soap tested on the leather moistened with water as well as sandpaper. However, in the case of lower loads (3.79 kPa and 1.94 kPa), significant differences for Stiction were only between the leather moistened with water (leather + water) as compared to the dry leather and sandpaper. There were no significant differences found for the test soap on the dry leather or sandpaper. For all tested loads, the lowest Stiction was found for soap tested on the leather moistened with water. The value of the initial friction (Stiction) of the soap in the case of this surface with the load of 500 g was between the minimum of 0.97 N and the maximum of 1.37 N, while for the load of 200 g, the minimum Stiction was 0.41 N while the maximum 0.58 N. In the case of the minimum load of 100 g, the minimum value of this friction for the soap was 0.36 N, while the maximum equaled 0.48 N (Table 1).

**Table 1.** Statistical analysis of the initial friction (Stiction) of samples depending on the surface and load.

| Surface | Load Applied on the Sample * [g] | Min. Stiction [N] | Max. Stiction [N] | Stiction S.D. |
|---|---|---|---|---|
| Leather | 505 | 1.664 | 2.399 | 0.319 |
| | 205 | 0.853 | 1.902 | 0.414 |
| | 105 | 0.893 | 1.207 | 0.115 |
| Leather + water | 505 | 0.966 | 1.371 | 0.152 |
| | 205 | 0.411 | 0.583 | 0.083 |
| | 105 | 0.355 | 0.479 | 0.049 |
| Sandpaper (320) | 505 | 3.195 | 5.316 | 0.960 |
| | 205 | 1.279 | 2.056 | 0.312 |
| | 105 | 0.926 | 1.612 | 0.254 |

* The sample loads were 500, 200 and 100 g. The total sample load was equal to the sum of the weight of the sinker and the weight of the socket, thus 505 g, 205 g and 105 g.

The differences for the various surfaces were significant for measurements completed with the highest pressure applied (9.33 kPa), where the mean Stiction value for the soap tested on the surface of water moistened leather was 1.17 N, for the surface of the dry leather it was 1.99 N, while for the sandpaper it equaled 4.42 N.

The dynamic friction (Friction) of the analyzed soap samples depending on the load applied is presented in Figure 6. In this case, for each surface, as in the case of the initial friction (Stiction), the greatest significant differences were recorded between the measurements of the dynamic friction carried out under the pressure of 9.33 kPa and the measurements with the applied pressure of 3.79 kPa and 1.94 kPa. Significant differences in dynamic friction were also recorded between the surfaces when the pressure applied equaled 3.79 kPa, while in the case of the lowest load of 1.94 kPa, no significant differences were observed between the dry leather and sandpaper. For all tested loads, as in the case of Stiction, the lowest friction value was characteristic of the soap tested on the surface of leather moistened with water, where the average values of this friction ranged between 0.13–0.33 N (Table 2).

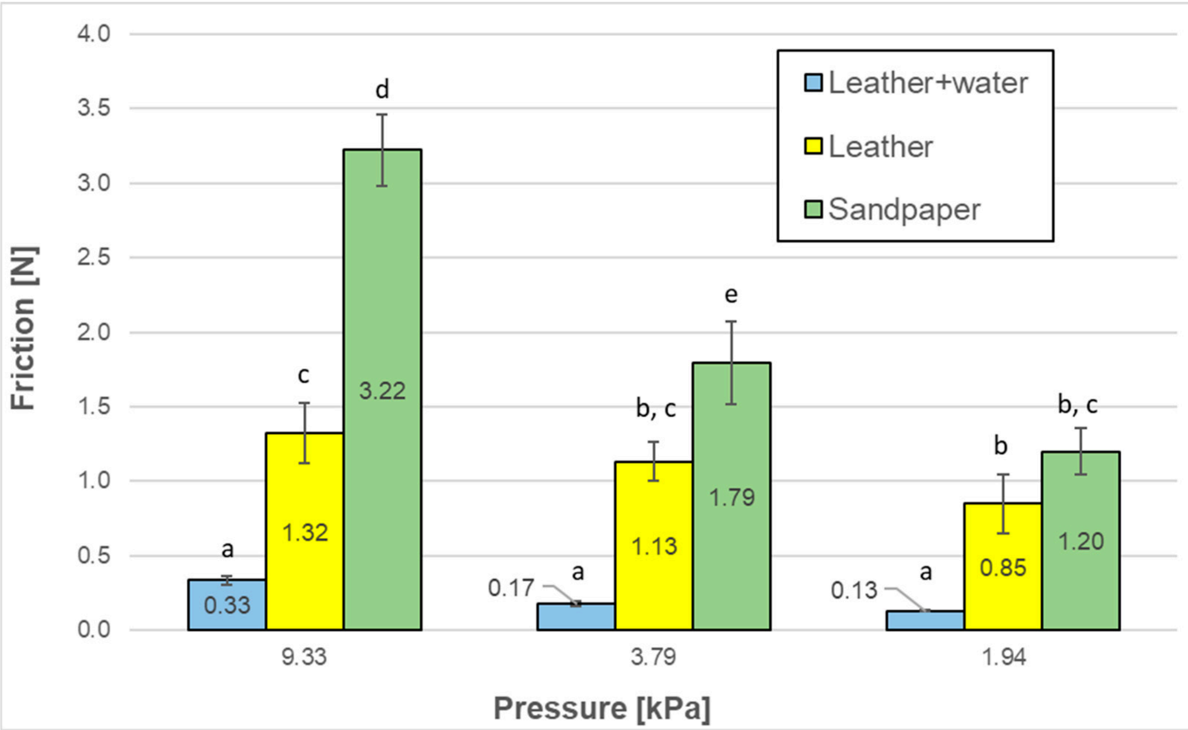


**Figure 6.** Dynamic friction of the analyzed soap samples. a–e the same letters indicate belonging to one homogeneous group (α = 0.05).

**Table 2.** Statistical analysis of the dynamic friction (Friction) of samples depending on the surface and load.

| Surface | Load Applied on the Sample * [g] | Min. Friction [N] | Max. Friction [N] | Friction S.D. |
|---|---|---|---|---|
| Leather | 505 | 1.040 | 1.583 | 0.203 |
| | 205 | 0.923 | 1.267 | 0.132 |
| | 105 | 0.616 | 1.077 | 0.198 |
| Leather + water | 505 | 0.306 | 0.360 | 0.026 |
| | 205 | 0.158 | 0.202 | 0.018 |
| | 105 | 0.123 | 0.132 | 0.004 |
| Sandpaper (320) | 505 | 2.891 | 3.542 | 0.241 |
| | 205 | 1.568 | 2.258 | 0.277 |
| | 105 | 0.992 | 1.406 | 0.155 |

* The sample loads were 500, 200 and 100 g. The total sample load was equal to the sum of the weight of the sinker and the weight of the socket, thus 505 g, 205 g and 105 g.

The smallest values were for the load of 100 g and the highest for the load of 500 g. The standard deviation was the highest in the case of sandpaper and dry leather.

The differences between the measurements of the dynamic friction work (Figure 7) of the soap samples were similar to those of the dynamic friction itself.

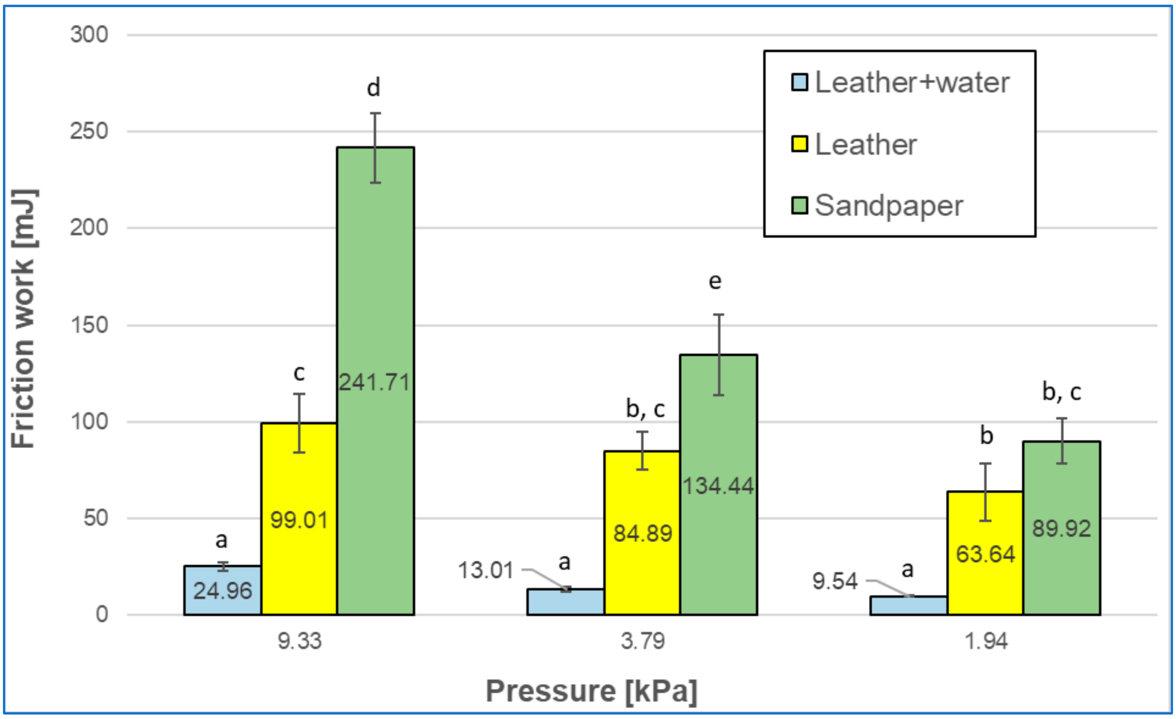


**Figure 7.** Dynamic friction work of the analyzed soap samples. a–e the same letters indicate belonging to one homogeneous group (α = 0.05).

Considering different surfaces tested they were the most significant for the highest pressure, i.e., 9.33 kPa. The work of dynamic friction at this highest load was the lowest for the soap tested against the surface of the leather moistened with water and equaled 24.96 mJ, the average for the soap tested on the dry leather was 99.00 mJ, while the highest value was recorded for the soap tested on the sandpaper (241 mJ). Significantly lower values (Table 3) were obtained for the average load (3.79 kPa). They equaled 13.01 mJ for the leather moistened with water, 84.89 mJ for the dry leather, and 134 mJ for the sandpaper, respectively. At the lowest load (1.94 kPa), the values of work were 9.54 mJ, 63.64 mJ, and 89.92 mJ for the water moisturized leather, dry leather, and sandpaper, respectively.

The static friction coefficient (Us) (Figure 8), similar to the static or dynamic friction, was the lowest for the soap tested on the leather moistened with water. It was 0.023 for the 200 g and 500 g load and 0.040 for the 100 g load. Significantly higher values of this coefficient were obtained for the soap samples tested on the dry leather and on the sandpaper (Table 4).

**Table 3.** Statistical analysis of dynamic friction work of samples depending on the surface and load.

| Surface | Load Applied on the Sample * [g] | Min. Dynamic Friction Work [mJ] | Max. Dynamic Friction Work [mJ] | Dynamic Friction Work S.D. |
|---|---|---|---|---|
| Leather | 505 | 78.029 | 118.700 | 15.235 |
| | 205 | 69.211 | 95.023 | 9.873 |
| | 105 | 46.230 | 80.749 | 14.836 |
| Leather + water | 505 | 22.915 | 27.033 | 1.934 |
| | 205 | 11.860 | 15.187 | 1.317 |
| | 105 | 9.241 | 9.921 | 0.318 |
| Sandpaper (320) | 505 | 216.813 | 265.621 | 18.063 |
| | 205 | 117.600 | 169.358 | 20.794 |
| | 105 | 74.412 | 105.464 | 11.606 |

* The sample loads were 500, 200 and 100 g. The total sample load was equal to the sum of the weight of the sinker and the weight of the socket, thus 505 g, 205 g and 105 g.

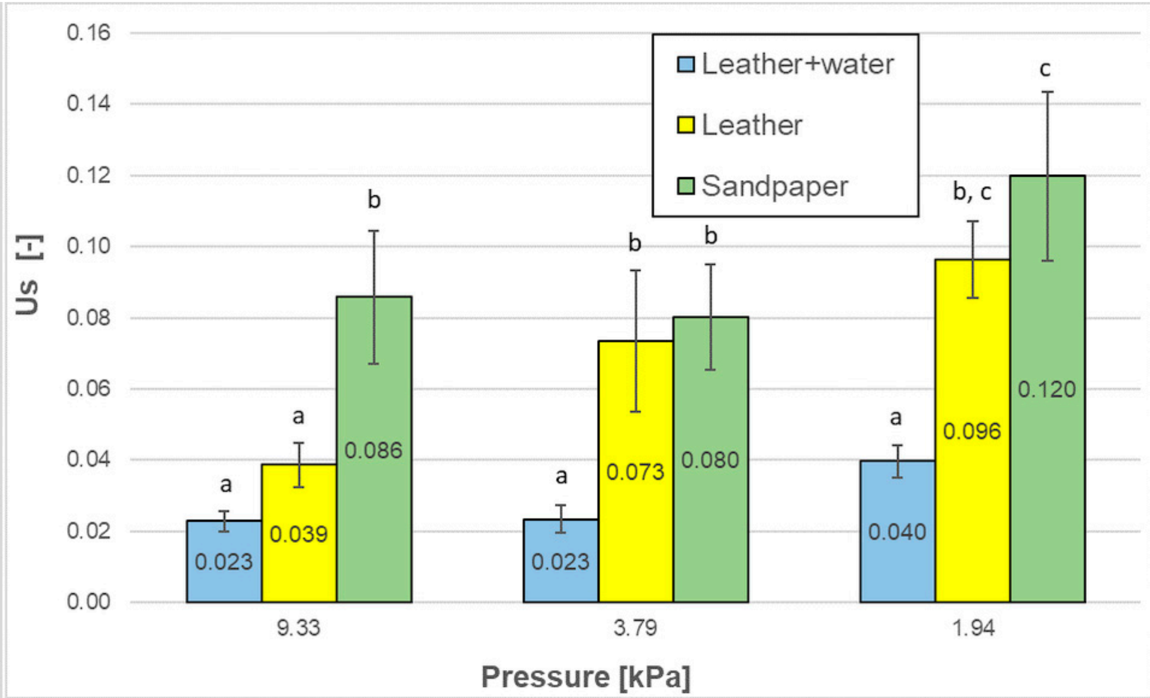


**Figure 8.** Static friction (Stiction) coefficient (Us) of analyzed soap samples. a–c the same letters indicate belonging to one homogeneous group (α = 0.05).

**Table 4.** Statistical analysis of the static friction coefficient Us of samples depending on the surface and load.

| Surface | Load Applied on the Sample * [g] | Min. Us | Max. Us | Us S.D. |
|---|---|---|---|---|
| Leather | 505 | 0.032 | 0.047 | 0.006 |
| | 205 | 0.041 | 0.091 | 0.020 |
| | 105 | 0.083 | 0.113 | 0.011 |
| Leather + water | 505 | 0.019 | 0.027 | 0.003 |
| | 205 | 0.020 | 0.028 | 0.004 |
| | 105 | 0.033 | 0.045 | 0.005 |
| Sandpaper (320) | 505 | 0.062 | 0.103 | 0.019 |
| | 205 | 0.061 | 0.098 | 0.015 |
| | 105 | 0.086 | 0.151 | 0.024 |

* The sample loads were 500, 200 and 100 g. The total sample load was equal to the sum of the weight of the sinker and the weight of the socket, thus 505 g, 205 g and 105 g.

The values of static friction coefficient of the soap tested on dry leather were 0.039, 0.073, and 0.096 for 500 g, 200 g and 100 g, respectively. In contrast, the values of the static friction coefficient for the soap tested on sandpaper were the largest recorded in the experiment and equaled 0.086, 0.080, and 0.120, respectively for a decreasing load of 500 g, 200 g and 100 g.

The dynamic friction coefficient (Figure 9) of the soap tested on various surfaces increased with increasing load.

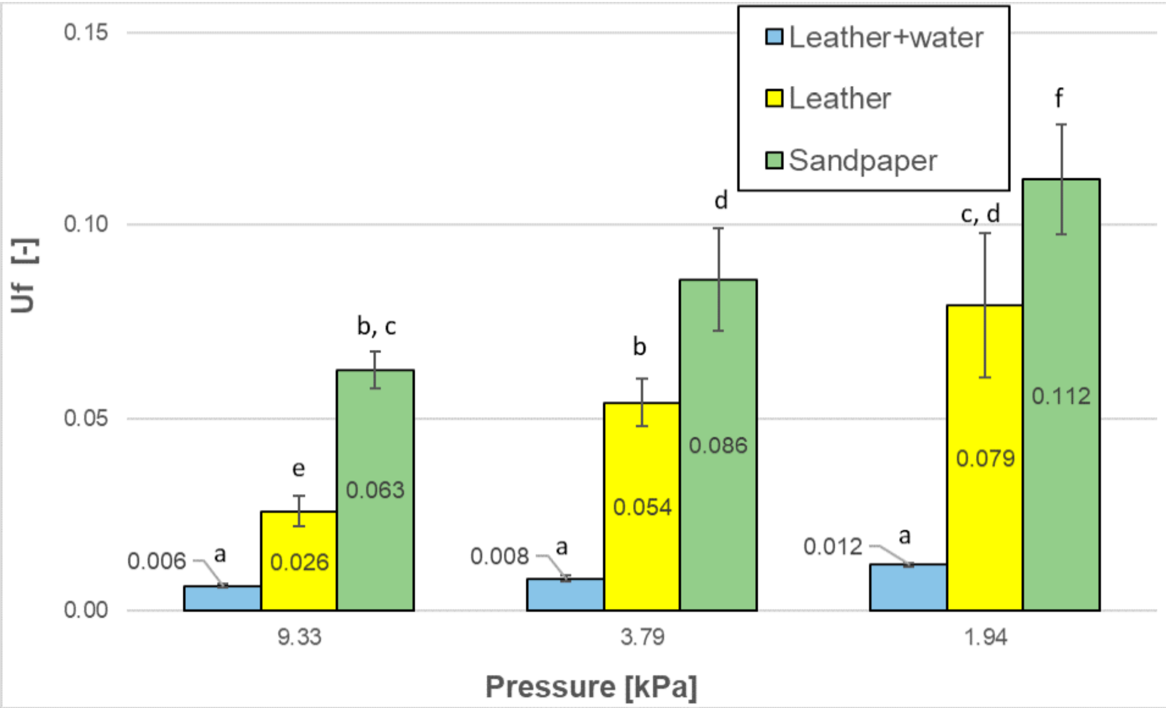


**Figure 9.** Dynamic friction coefficient (Uf) of the analyzed samples. a–f the same letters indicate belonging to one homogeneous group ($\alpha = 0.05$).

As in all the above examples, the lowest values of the dynamic friction coefficient were obtained for the soap tested on the leather moistened with water. They were in the range of 0.006 to 0.012. Then significantly higher values of the coefficient were obtained for the soap tested on the dry leather ranging from 0.039 to 0.096. The highest dynamic friction coefficients were within the range 0.080 to 0.120 and they were recorded for sandpaper (Table 5).

**Table 5.** Statistical analysis of the dynamic friction coefficient Uf of samples depending on the surface and load.

| Surface | Load Applied on the Sample * [g] | Min. Uf | Max. Uf | Uf S.D. |
|---|---|---|---|---|
| Leather | 505 | 0.020 | 0.031 | 0.004 |
| | 205 | 0.044 | 0.061 | 0.006 |
| | 105 | 0.058 | 0.101 | 0.018 |
| Leather + water | 505 | 0.006 | 0.007 | 0.001 |
| | 205 | 0.008 | 0.010 | 0.001 |
| | 105 | 0.012 | 0.012 | 0.000 |
| Sandpaper (320) | 505 | 0.056 | 0.069 | 0.005 |
| | 205 | 0.075 | 0.108 | 0.013 |
| | 105 | 0.093 | 0.131 | 0.014 |

* The sample loads were 500, 200 and 100 g. The total sample load was equal to the sum of the weight of the sinker and the weight of the socket, thus 505 g, 205 g and 105 g.

Considering the results of the linear dynamic friction sliding distance (Figure 10), in most cases, no significant differences were observed between this parameter for different surfaces at various loads (500–100 g). The values of this parameter ranged from 133.2 to 154.7 N × mm (Table 6).

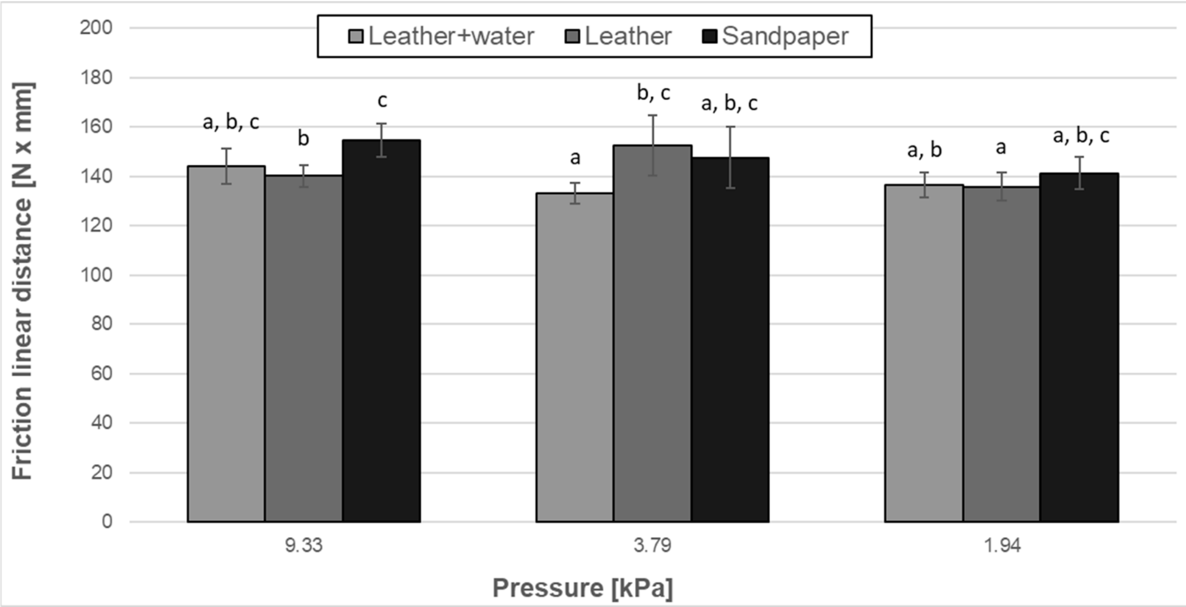


**Figure 10.** Linear distance of dynamic friction of the analyzed soap samples. a–c the same letters indicate belonging to one homogeneous group (α = 0.05).

**Table 6.** Statistical analysis of the linear dynamic friction sliding distance of the samples depending on the surface and load.

| Surface | Load Applied on the Sample * [g] | Min. Linear Distance of Friction [N × mm] | Max. Linear Distance of Friction [N × mm] | Linear Distance of Friction S.D. |
|---|---|---|---|---|
| Leather | 505 | 136.032 | 146.524 | 4.316 |
| | 205 | 139.573 | 166.740 | 12.287 |
| | 105 | 130.178 | 142.577 | 5.666 |
| Leather + water | 505 | 133.130 | 151.216 | 7.141 |
| | 205 | 128.610 | 137.610 | 4.049 |
| | 105 | 129.052 | 141.168 | 5.037 |
| Sandpaper (320) | 505 | 146.392 | 164.026 | 6.897 |
| | 205 | 135.707 | 162.025 | 12.270 |
| | 105 | 131.659 | 148.770 | 6.427 |

* The sample loads were 500, 200 and 100 g. The total sample load was equal to the sum of the weight of the sinker and the weight of the socket, thus 505 g, 205 g and 105 g.

## 4. Discussion

In our research, it was observed that the values of soap friction parameters, including static friction, dynamic friction and friction coefficients, depend on the type of surface the tests were performed on. Such relationships were also observed in other studies. Differences in the static friction coefficient obtained in the tests between the pad covered with rubber of different granulation and other surfaces were observed. These surfaces were materials such as glass, PVC, wood, concrete, marble, ceramics and sandpaper [11]. As explained by Ivkovic et al. [16] the friction between two solids depends on the contact conditions, including the surface microtopography in the contact zone. The static friction coefficient depends on many factors: mechanical properties of the material, surface roughness, mutual dissolution of materials, contact time, lubricant film properties, tribosystem elasticity, etc. In other studies [29] presenting a model predicting static friction for elastic-plastic contact of rough surfaces, a strong dependence on the external force and the nominal contact surface on the static friction coefficient was observed. In our research, the lowest values of friction or coefficients of friction, both static and dynamic, were obtained for the leather moistened with water. Kogut and Etsion [29] indicate that the main dimensionless parameters influencing the static friction coefficient are the plasticity index and the adhesion parameter. When examining the frictional behavior of a pneumatic cylinder, it was observed that static friction and dynamic friction forces decreased with increasing humidity [30]. Other authors [31] studying hydrogels show that surface friction depends on contact conditions and the level of surface hydration. Low friction was achieved with high surface hydration. As shown [32], the dynamic friction force is related to the volume of water droplets, the sliding velocity and the mechanical properties of the surface. On the other hand, studies [33] of lubricants used in lenses that have a higher water content showed that they are characterized by a low coefficient of friction by producing and maintaining a polymer surface gel. The lubricity of such gels is often attributed in addition to their high water content, also to their high permeability, their low elastic modulus and their ability to form a water film on a sliding surface. In our study, it was observed that in most cases sandpaper was the most frictional surface. In some cases, especially with lighter loads, there were no significant differences between the dry leather and sandpaper. In the measurements of the friction coefficient conducted by Katsumat et al. [34] it was found that the most appropriate method of increasing the frictional forces is the introduction of sandpaper. Sandpaper is a well-known anti-skid material [35].

## 5. Conclusions

The conducted research has shown that the developed attachment and the methodology of friction tests allows for its use in quality assessment, including sustainable processing.

It was demonstrated that with this adapter, it is possible to measure the friction of the soap samples at tested pressure of 9.33 kPa, 3.79 kPa, and 1.94 kPa.

It was observed that the developed adapter for testing the friction coefficient has the following advantages:

1. Ensures easy and quick assembly of the tested sample,
2. Allows for quick exchange and stable operation in both directions of measurement, i.e., pushing and pulling the sample
3. Allows the application of different sample loads
4. Allows to perform friction analyzes on various surfaces (leather, skin moistened with water, sandpaper)
5. Allows the use of various lubricants (e.g., surface wetting or lubrication).

**Author Contributions:** Conceptualization, J.M.; methodology, J.M., M.P. and P.S.; software, J.M.; validation, J.M., and K.Z.; formal analysis, J.M., investigation, J.M., and M.W.; resources, R.R., and M.P.; writing—original draft preparation, J.M., and R.R. writing—review and editing, R.R.; visualization, J.M.; supervision, P.S.; project administration, K.Z.; funding acquisition, P.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

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