

Friction forces on human finger skin

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Abstract. The prehension of the small objects with the human fingers is depending on the friction and adherence between finger's skin and object's surface. The design of finger pads for robotic and prosthetic hands must simulate both the human finger friction and adherence and elastic deformation, especially for small objects. In this paper, the authors have experimentally investigated the friction forces and friction coefficients in a dry sliding contact tribosystem using Microtribometer CETR UMT-2. A steel cylinder was sliding on the human finger with speeds between 0.5 to 10 mm/s at normal loads up to 10 N. The results showed that the friction coefficient increases with the sliding speed and decreases with the normal load. Also, it was evidenced the presence of the adherence and sliding zones during the laterally cyclic movement of steel cylinder as function of the normal loads and sliding speeds. A general equation for the friction coefficient as function of sliding speed and normal load has been obtained. Therefore, the experimental results offer important information to select the adequate artificial skin materials for robotic finger pads, often overlooked, with relatively simple shapes and mechanical properties typically used.

1. Introduction

The friction and adherence between human fingers and various surfaces has been studied using several methods.

The friction and stick-slip behavior between the index finger and a plane wet glass probe have been studied by [1]. They determined the mean friction coefficient variation as function of normal finger force and sliding speed. Values of friction coefficient in range of 1.4 to 0.2 for the normal force increasing from 0.1 N to 10 N have been obtained. Also, the friction coefficient values between 1.4 to 0.2 have been obtained by the sliding speed increasing from zero to 1.5 m/s [2]. It was studied in vivo the friction and deformation of the human forearm skin by using a pin with a smooth ball in the top. The authors evidenced the two components of the total friction force as a sum of an adhesion force and a skin deformed force in front of the ball during the sliding process. The skin deformation and relaxation forces for a reciprocating-sliding of the ball in a cycle with positive and negative speed has been obtained by the authors for various ball diameters between 2 and 5 mm and normal force between 0.19 to 0.5 N. The friction coefficient resulted from the adhesion force varied between 0.7 and 1.5. Using a portable handheld device Veijgen *et al.* [3] studied the friction coefficient between some human skin surfaces and a cylinder realized from various materials. Depending of the cylinder material (PTFE, Aluminium, Polyamide), person gender, hydration of the skin and various skin surfaces on forearm and fingers, the friction coefficient have an important variation between 0.02 to 1.5. Another study [4] simulated the friction between the textiles materials and foot skin for the sports equipments. The authors experimentally studied the friction between artificial leather materials with a friction behavior similar to human skin and textile materials. The obtained friction coefficient varied



between 0.28 to 0.38 as function of apparent contact pressure. In his PhD thesis Thomlinson [5] investigated the friction between human fingers and flat surfaces and obtained the friction coefficients for a lot of materials (glass, steel, plastics, rubber). The author evidenced that the total friction force in a finger skin-plate surfaces tribological system is a sum of adhesive, skin deformation, capillary and deformation of finger ridges forces. To avoid the skin deformation in the front of a ball Barnea *et al.* [6] experimentally studied the friction between various small cylinders and finger skin. The method consists, in a first step, to introduce an initial deformation on the finger tissue with the cylinder using small normal loads and, in the second step, it was realized the cyclic sliding of the cylinder on the finger, maintaining the normal load initially imposed. The minimum friction coefficient values have been obtained for PTFE cylinder, from 0.2 to 0.45 for normal load of 4 N and 1 N, respectively.

In the present paper the authors developed the methodology and a lot of experimental results for the friction and adherence between a small steel cylinder and the human finger in a cyclic sliding motion under normal loads between 1 to 10 N and sliding speeds between 0.5 to 10 mm/s.

2. Experimental methodology and equipments

The experiments were realized in the Tribology Laboratory from the Mechanical Engineering Faculty of Iasi using the facilities of the microtribometer CETR UMT-2. In figure 1 (a) is presented a general view of the microtribometer with the directions of the normal and tangential forces and in figure 1 (b) is presented a detail with the cylinder and finger contact. The forces were detected by a special sensor and all data including normal and tangential forces, friction coefficient, sliding speed and time are captured in the computer by an adequate program.

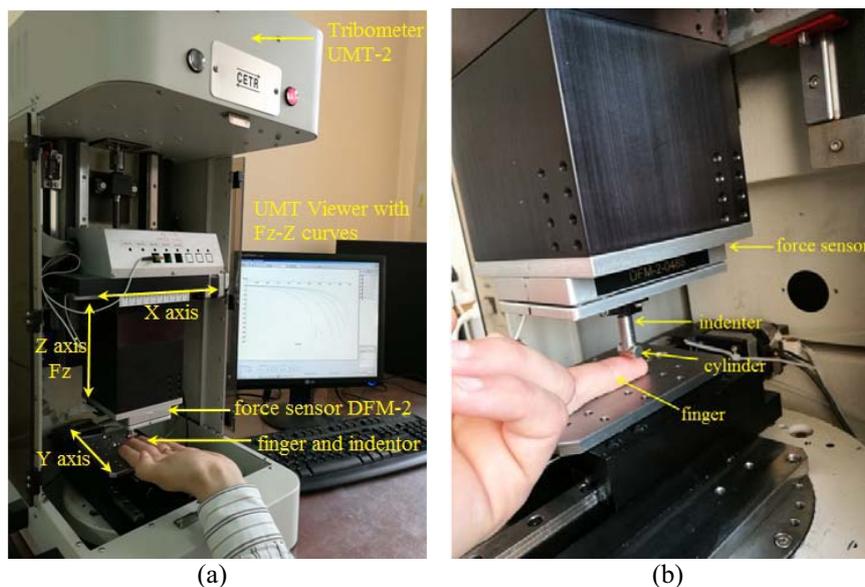


Figure 1. Experimental equipments.

The steel cylinder has the diameter of 6.96 mm and the length of 38.6 mm with the roughness $R_a = 0.06 \mu\text{m}$. The direction of the cylinder is perpendicular on the finger and the cylinder sliding on the finger surfaces have imposed constant sliding speeds of 0.5, 1, 5 and 10 mm/s. The cylinder is pressed on the finger with three normal forces F_z : 1 N, 5 N and 10 N. Depending on the sliding speeds, the number of the sliding cycles on the laterally distance from -10 mm to 10 mm varies between 2.5 to 50 cycles. The tangential forces F_x are measured in both directions, positive and negative values have been obtained, according to sliding direction. The friction coefficient, indicated by COF in the program has only positive values.

3. Experimental results and comments

To evidence the influence of the normal load and sliding speed on the friction forces and friction coefficient between cylinder and dry finger skin experimental diagrams have been obtained. Figures 2 and 3 describe the registered variation of the tangential forces F_x as function of sliding time for two normal loads: $F_z = 1$ N and $F_z = 10$ N, respectively. So, it is evidenced the influence of the normal load on the variation of the tangential force F_x for positive and negative sliding cycles. The sliding speed was 1mm/s for both two tests.

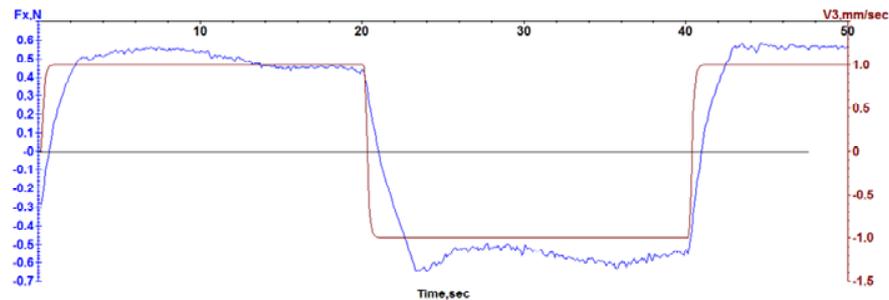


Figure 2. Friction force and sliding speed variations with the time for normal load $F_z = 1$ N and for a sliding speed of 1 mm/s.

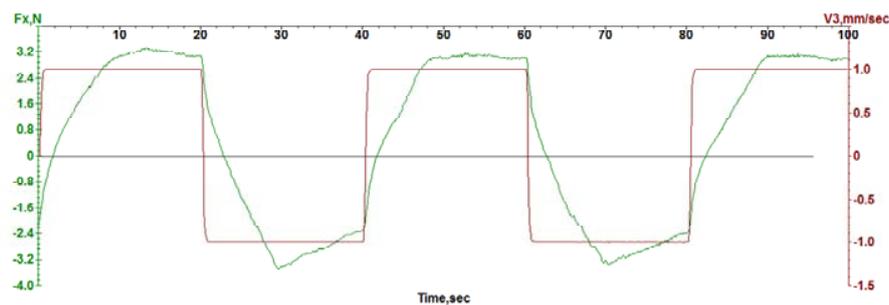


Figure 3. Friction force and sliding speed variations with the time for normal load $F_z = 10$ N and for a sliding speed of 1 mm/s.

The diagrams evidenced that, in a sliding cycle, the following mechanical phenomena have been produced: an adherence phase with deformation of the finger tissue, a sliding phase with a relative constant friction force F_x , a relaxation phase of the finger tissue by changing the direction of the sliding speed, a new adherence phase with increasing of the force by finger tissue deformation in opposite direction, a new sliding phase with a relative constant friction force F_x and the mechanical processes continue. For the normal force $F_z = 1$ N the deformation and relaxation phases are realized in 3.5 – 4 seconds and the sliding phase is dominant for complete cycle. For a normal force $F_z = 10$ N, the deformation and relaxation phases are realized in 9 – 10 seconds and the sliding phase is realised in 10-11 seconds. So, increasing of the normal load leads to the time increasing for deformation and relaxation phases and the time for sliding phase is decreasing. Also, increasing of the normal load F_z to 10 N, an asymmetric variation of the positive and negative friction forces has been observed. The asymmetric evolution of the friction forces obtained through the increasing of the normal force from 1 N to 10 N can be observed in figure 4 where are superposed the force-time diagrams for $F_z = 1$ N, 5 N and 10 N.

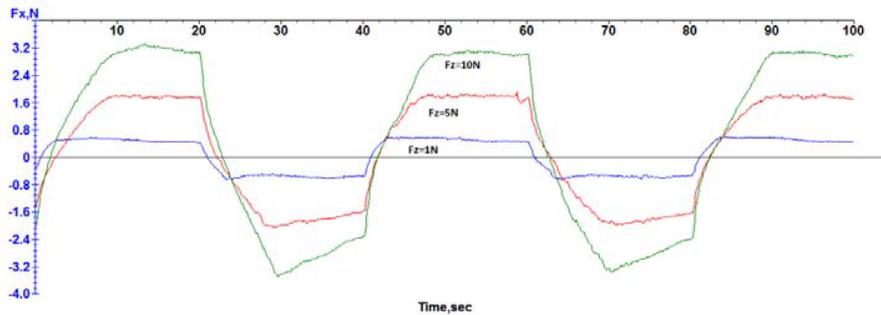


Figure 4. Variations of the friction force as function of sliding time, for normal loads $F_z = 1\text{ N}$, 5 N and 10 N and for a sliding speed of 1 mm/s .

In our opinion, the increasing of the normal force F_z determines the increases of the finger tissue deformation with a quantitative difference between the two sliding directions as result of no uniform finger internal structure.

The friction coefficient defined as the ratio between absolute value of tangential force F_x and normal load F_z has been considered only in the sliding phase and it is determined only by adherence between the finger skin and the cylinder.

Two diagrams for variation of the friction coefficient COF as function normal loads for two sliding speeds (2 mm/s and 10 mm/s) have been presented in the figures 5 and 6.

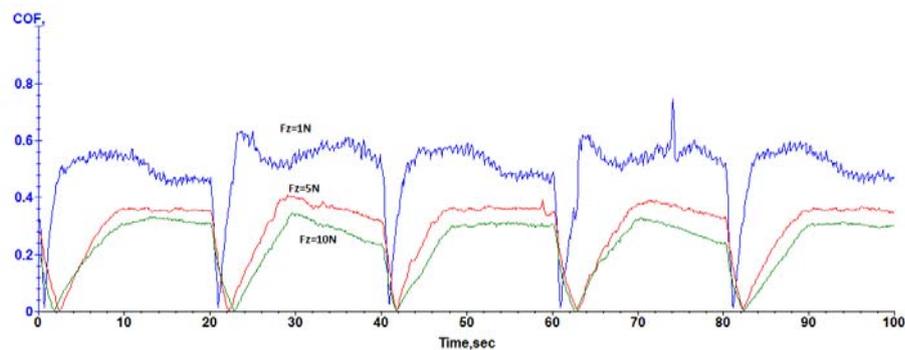


Figure 5. Variations of the friction coefficient as function of sliding time, for normal loads $F_z = 1\text{ N}$, 5 N and 10 N and for a sliding speed of 1 mm/s .

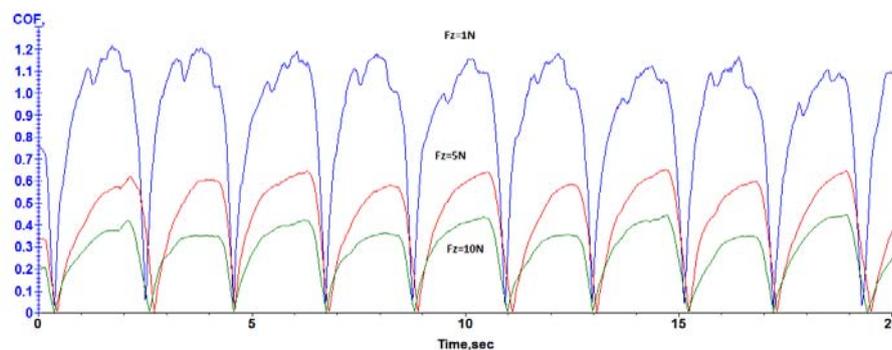


Figure 6. Variations of the friction coefficient as function of sliding time, for normal loads $F_z = 1\text{ N}$, 5 N and 10 N and for a sliding speed of 10 mm/s .

It can be observed important variations of the friction coefficient as function of normal load, F_z , and sliding speed, v . Average values of the friction coefficient experimentally determined for five sliding speeds and three normal loads have been presented in the table 1.

Table 1. Average values of the friction coefficient, COF

$v, \text{mm/s}$	$F_z=1\text{N}$	$F_z=5\text{N}$	$F_z=10\text{N}$
0.5	0.46	0.32	0.27
1	0.498	0.36	0.31
5	0.83	0.48	0.32
10	1.15	0.62	0.35

The variations of the friction coefficient as function of sliding speed and normal load have been presented in figure 7.

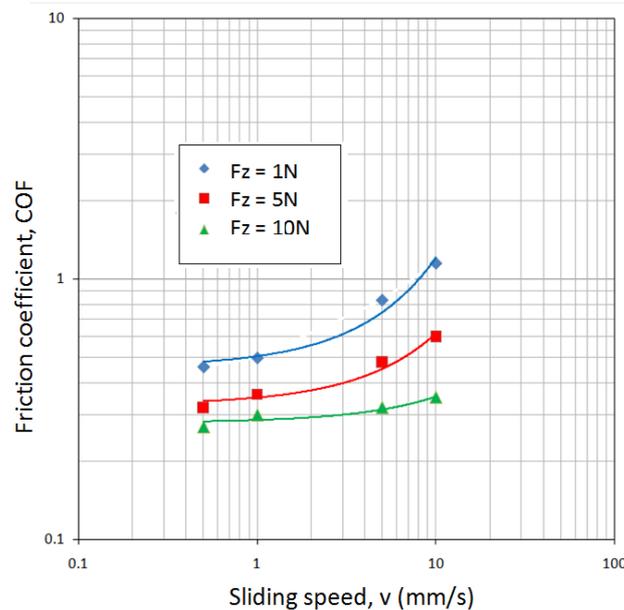


Figure 7. Variations of the friction coefficient as function of sliding speed and normal load.

By curve fitting the experimental values for friction coefficient COF, the following general equation for COF as function of sliding speed and normal load has been developed by authors:

$$COF(v, F_z) = F_1(F_z) \cdot \exp[v \cdot F_2(F_z)] \quad (1)$$

In equation (1) the functions $F_1(F_z)$ and $F_2(F_z)$ are depending only of the normal load and have the following equations:

$$F_1(F_z) = 0.459 \cdot F_z^{-0.212} \quad (2)$$

$$F_2(F_z) = 0.1049 - 0.0082 \cdot F_z \quad (3)$$

The errors between experimental values of COF presented in table 1 and similar values obtained by equations (1) - (3) are not exceeding 10%.

Based on the experimental results presented in table 1 and figure 7 following observations can be made:

- (i) The sliding speed increasing leads to the friction coefficient increasing. The increasing rate is dependent of the normal load.
- (ii) Increasing the normal force F_z determines the friction coefficient decreasing.
- (iii) The dependence between friction coefficient and normal load obtained by authors are in good agreement with the results obtained by Derler and Rotaru [1] for sliding of index finger on wet flat glass in the similar normal load range 0.1 to 10 N.

4. Conclusions

Experimental investigations to determine the friction and adherence behavior of the human finger skin in contact with a steel cylinder have been realized by the authors.

The experimental method developed by the authors allows the friction coefficient to be determined by maintaining the contact pressure constant.

The experiments were realized for normal loads between 1N and 10N and for sliding speeds between 0.5mm/s and 10mm/s.

Both normal load and sliding speed influence the friction and adherence behavior of the finger skin.

When the normal load increases, the friction coefficient decreases. The sliding speed increasing leads to the friction coefficient increasing.

Friction coefficients between 0.27 and 1.15 have been obtained for the normal forces and sliding speed studied interval.

A general equation for the friction coefficient as function of sliding speed and normal load has been obtained.

5. References

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