ISSN 1392-1134/ eISSN 2345-0371
Agricultural Engineering, Research Papers, 2017, Vol. 49, 1-7 p.

EXPERIMENTAL PREDICTION OF CREEP AREA AND STATIC FRICTION BETWEEN BRASS MATERIAL AND COW SKIN

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Abstract: In this current study, a twist static frictional behavior was experimentally studied by using different shapes of an indenter tip (circular, square, and triangular cross sectional area) all are made from brass and applied load (1 and 2 N). The creep area and the static coefficient of friction between cow skin and tips were recorded at times (1, 2, 3, and 4 minutes). The gained experimental results showed that the creep area and the coefficient of friction of cow skin increased as the time increased for both applied loads. The circular shape has maximum creep area while the twist static coefficient of friction was minimum compared to that produced by the others shapes.
Keywords: Twist static friction, cow skin, creep area, endoprosthesis support

Received 2017-08-21, accepted 2017-12-18

Introduction

In the last two decades, there are several studied have compared the mechanical and physical properties of skins from different sources when tested in ex vivo, and some of the studies have analyzed the Vivo skin properties. Several studies [1-3] investigated and compared different types of skin, the first one is human skin in-vivo and the others are animals skin, taking into account many important engineering features like mechanical behavior, friction circumstances, and theories that explaining in details deformation and adhesion components of friction. They reported that some of the animal's skin has similar mechanical properties to the human skin and could be used as fabrics for amputee persons with above knee amputation (AK), furthermore, they concluded that the behavior of these skins under was totally depended on the animals age and wide-ranging boundary conditions.

In the same object, Cheng et al [4] theoretically studied the indentation of standard viscoelastic solids by using three-element viscoelastic material such as an axisymmetric, flat-ended indenter under flat-punch indentation of a viscoelastic half-space as the boundary conditions. The results from exploratory creep and relaxation tests of two materials showed that the three-element analytical model was used of flat-ended punch indentation into viscoelastic materials are suitable. Kussay et al [5] proposed a model to measure the adhesion and hysteresis and the measurement of some mechanical properties between human skin and some artificial materials.

The model was dynamically analyzed for the damper and explained the effect of the geometric damper form on the coefficient of friction constant and kinetic [6].Kussay et al [7] has employed ex-vivo cow skin as a raw biomaterial to investigate mechanical coefficient of friction and its proposed mathematical relationship with the angular velocity of an indenter under a specified range of the applied direct pressure plus to measure the obtained trace of the direct contact area. Gained results predict that the coefficient of friction drops down as the pressure rises up but the inverse proportional with respect to angular velocity.

The main movements or tendencies of movement between the skin and the endoprostheses (hand or foot) are an oscillating slip and oscillating pivoting (spin, twist). Transmission of forces in the presence of these movements is the main cause of skin damage and pain. The twist friction has some particular of the shape of the contact, the speed at the contact points and the distribution of the tangential stresses at known normal loads. The viscoelastic properties of the skin, the distribution of pressures and superficial energy upon contact with the other element of the tribosystem contribute to the twist friction and, implicitly, to certain values of the conventional twist friction coefficient.

The constructive endoprosthetic solutions are continually upgraded [8]. Thus, the friction between the human skin and rigid support of the prosthesis is considered essential for functioning and comfort. The main conditions are reduced slip and twist friction, more uniform contact pressure and high damping at dynamic loads. The property of biocompatibility of materials is essential. A new solution is proposed for "endoprosthesis support", using the cow skin on a rigid support. This support, considered rigid, has much higher elasticity than the skin. The brass is used to determine the rheological properties of viscoelastic materials such as rubber or foam, which can model the flowing and deformation phenomena of the skin (rheological models).

In order to finalize the new "support" constructive solution, the present paper analyzes experimentally the static twist friction and, in part, the creep phenomenon at the torsional load-step. The geometry of the "support" surface is evaluated by area and perimeter. In this sense, it is proposed to compare experimentally three simple geometric shapes (circle, square, and triangle) with the same area.

The present paper proposes an experimental analysis of the cow skin creep viscoelastic behavior and the twisted behavior in contact with rigid material (brass). The skin's behavior of twist friction, with material (greater elasticity than skin), highlights the friction adhesion component. The mechanical component of the friction is dependent on hysteresis losses and the distribution of contact pressure. The static twist friction torque is determined as a function of the constant loading time, the shape of punch, at the same average contact pressure.

The evolution of the perimeter of the contact surface after stopping the load (step load) characterizes the twisted creep. For rigid artificial punch, choose the flat surface with rounded edges with a small radius (0.5 mm). The surface shapes are chosen to be circular, square and triangle equilateral with the same area and, obviously, the different perimeters.

Practical part

A four balls machine coupled to an electric motor and electric control switch used in this study is presented before adding a new the method to measure the test as shown in Fig.1. The possible movement between skin and punch is twisting (spin) three different indenter shapes (circle, square and triangle), all made of brass having the same area equal to16 mm^2 were used to apply the load on the material- see Fig. 2A.

The pieces of skin with dimensions (25x25x4) from one-year-old cow male were used. These pieces were washed with fresh water without any chemical agents and all hairs were removed from the surface by shaving in one direction (see Fig. 2B). These pieces were placed in a special arm of device. A Nikon microscope was used together with a special camera to get a clear picture of the piece before and after the load was applied in order to make a comparison.

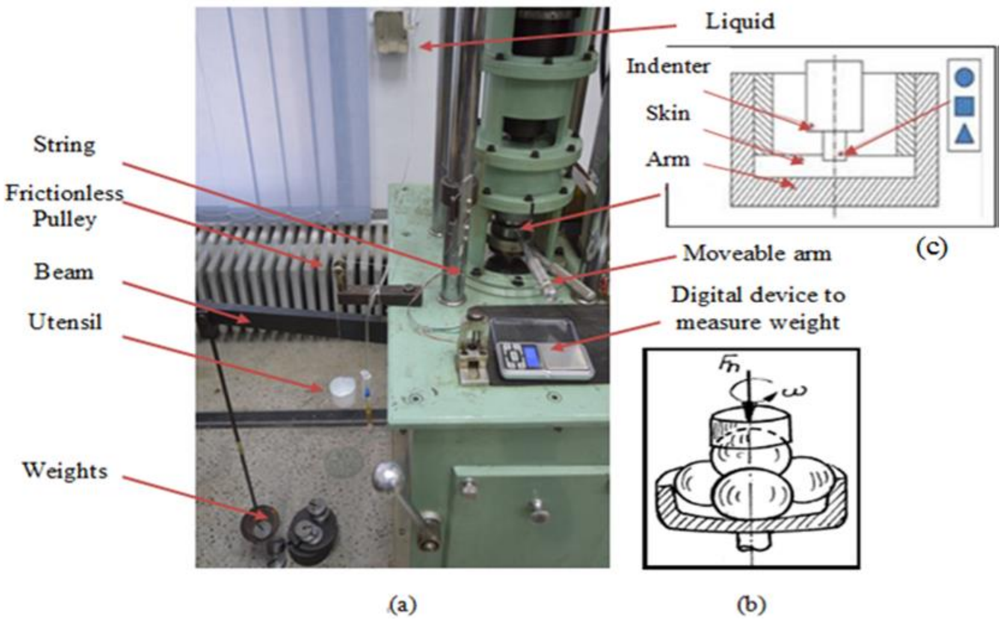

Fig. 1. The machine four balls device: (a) Image of the test device during the experiment explaining the contact with the skin**;** (b) Original indenter of the device; (c) New device for skin

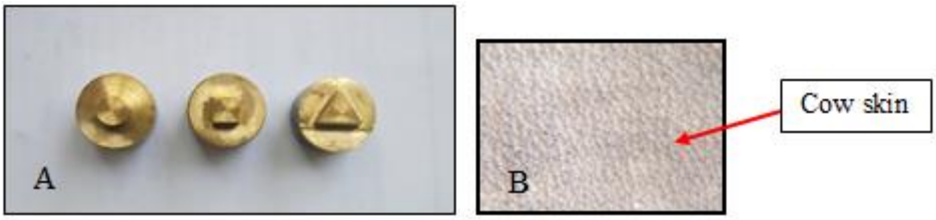

Fig. 2. (A) Types of the utilized indenters from brass material (B) Image of the utilized skin.

Procedure of test

A piece of cow skin was placed in the device in the specified place as shown in Fig 1c. The indenter shape of a circle (radius R_o) indenter was fixed and the normal loads (1 and 2 N) were applied. In order to determine the conventional coefficient of static twist friction, proceed as follows: tangentially the torque measuring lever is loaded with variable weights with a very little increase (drops of water) until the lever begins to move continuously. It is considered as a moment of static friction, the moment generated by the weight of the water in the collector immediately before the twist motion begins. The conventional friction coefficient is defined as the ratio between reduced friction force and normal force. The reduced friction force is determined on the basis of the static friction torque and the contact radius. For the circular surface, the radius of contact is appreciated by the radius of the circle, and for the surfaces of the square shape and the equilateral triangle, the contact radius is considered as the average of the radii of the inner circle and outer circle for square or triangle.

In order to make the arm begin or try to begin moving by adding water W_{Liquid}, resulting as a force F_{Static}. The piece was left for one minute to read the real contact area. The test was repeated three times with the same operating conditions to reduce the variations. At the same operating conditions, the test was repeated for different durations T (2, 3 and 4 minutes). Then the applied load was changed to 2 N and all the steps were repeated. The test results are presented in table 1. The indenter was changed to the square (length L_{so}) and then to the triangle (L_{to}) shapes and all the steps mentioned were repeated.

We shall the twist friction coefficient (μ_t) is calculated based on the "$\boldsymbol{r_{sf}}$ **-** specific friction radius"

$$\mu_t = \frac{M_{ft}}{F_n r_{sf}} \tag{1}$$

where M_{ft} is the friction torque, experimentally measured on the modified 4 ball machine and F_n is the normal contact force introduced.

The specific friction radius **($\mathbf{r_{sf}}$)** is defined as follows:

- For a circular radius surface r, the friction moment is determined by integrating frictional stresses into an elementary ring. Given the uniform distribution of the contact pressure (p_n) and a friction coefficient independent of the speed, the friction moment is

$$M_{ft} = \mu_t F_n \frac{2}{3} r = \mu_t F_n r_{sf} \tag{2}$$

where : $r_{sf} = \frac{2}{3} r$.

We obtained a similarly expression of specific radius of friction for square and triangular shapes.

The static friction torque is the moment of torsion immediately before initiating the rotation motion around the normal force axis. The sliding (slip) coefficient was determined for different rigid or elastic artificial materials in contact with the skin in other papers [2, 3].

Result and discussion

In this part of study, the results were collected under different operating times and different applied loads for three indenter shapes (square, circle, and triangle) at room temperature between (24-26 °C) and the humidity between (30-34 %), for brass material. The final results were acquired from the average of three stable and continuously measured values. The results as an example for circular shape are listed in table 1.

Table 1. Static friction torque and creep area at normal force (1 N and 2 N) for circle indenter (radius 2.256 mm) at one materials brass

Brass material							Brass material						
F_n (N)	T (min)	M_{fc} (N.mm)	$\mu_{f\ twist}$	R_r (mm)	A_r (mm^2)	δ (mm)	F_n (N)	T (min)	M_{fc} (N.mm)	$\mu_{f\ twist}$	R_r (mm)	A_r (mm^2)	δ (mm)
1N	1	3.735	2.483	2.29	16.47	0.32	2 N	1	4.278	1.422	2.31	16.76	0.38
	2	4.371	2.906	2.39	17.94	0.61		2	5.084	1.690	2.41	18.24	0.80
	3	5.037	3.349	2.45	18.85	0.95		3	5.425	1.803	2.475	19.24	1.24
	4	5.347	3.555	2.49	19.48	1.22		4	5.735	1.906	2.51	19.80	1.52

Where: M_{fc}: is the mean static friction torque (N.mm), for circle; $\mu_{f\ twist}$: twist static friction coefficient, A_r: creep area (mm^2), T: time (min), R_r: real radius in time, δ: depth (mm).

The creep parameter (*η*) is the specific dimension of deformed shape (radius for the circular shape- R_r, length for the square- L_{st}, and for the equilateral triangle- L_{tt}) in time divided to the nominal initial dimension (R_o, L_{so}, and L_{to}) : $\eta_c = R_r / R_o$, $\eta_s = L_{st} / L_{so}$, $\eta_t = L_{tt} / L_{to}$, where η_c, η_s, and η_t represent creep parameter to circle, square and triangle.

The variations of creep parameters at the step load depending on time are shown in Fig.3. The results were obtained for the circle, square and triangle indenter shapes at an applied load equal to 1 and 2 N for different durations (1, 2, 3, and 4 minutes). From this figure, the circle-shaped indenter has the highest creep parameter compared to the triangle and square shapes. This increase in the creep parameter in case of the circle shape may be the result of the fact that circle has lower perimeter compare to the other perimeters, leading to increasing, implicitely, in the contact area, thus resulting in increased creep parameter. The values obtained were 1.23 registered at 2 N applied load and 4-minute time, which is 4.07 % and 8.94 % higher than the creep parameter observed at square and triangle shapes respectively. Moreover, the circle indenter also registers higher creep parameter than other indenters when applying 1 N load, at the 4-minute time as shown in Fig.3.

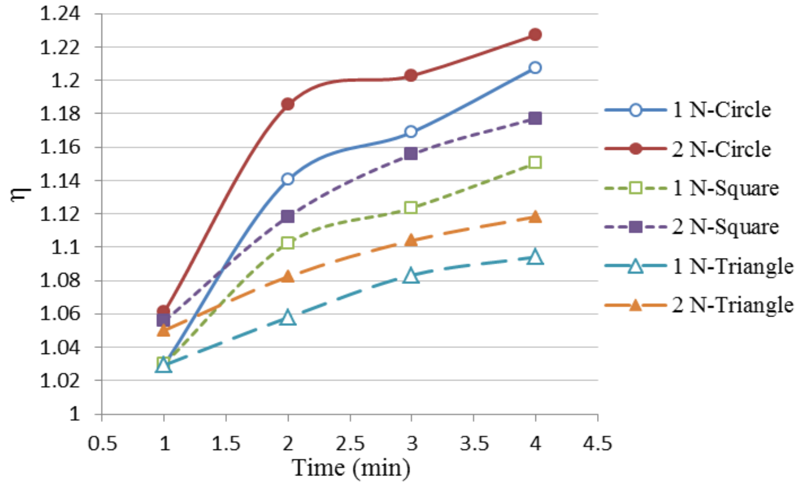

Fig. 3. Variations of creep parameter respect with step load and shape of punch for initial brass- skin contact.

Coefficient of friction. Fig. 4 presents the variation of the twist static friction coefficient depending on the duration when applying 1N and 2 N load through the square, circle and triangle indenter shapes (all indenter shapes have the same area equal to 16 mm^2). It has been shown that the twist static friction coefficient of triangle and square at load 2 N increased up to 4.763 and 4.670 respectively when the time increased from 0 to 4 minute. Whereas, the circle shape has a 1.906 twist friction coefficient, which is lower compared to the other shapes. This reduction may be due to the fact that circle shape has smaller perimeter than square and triangle shapes. The coefficient of friction for circle shape slightly increased with time.

For static sliding friction coefficients of the skin on rigid metallic materials (1.5…3) were obtained by Derler et al.[9]. The sliding kinetic friction coefficients for clean and degreased skin are in the order of magnitude 0.8 ... 1.4 [3], [9, 10].

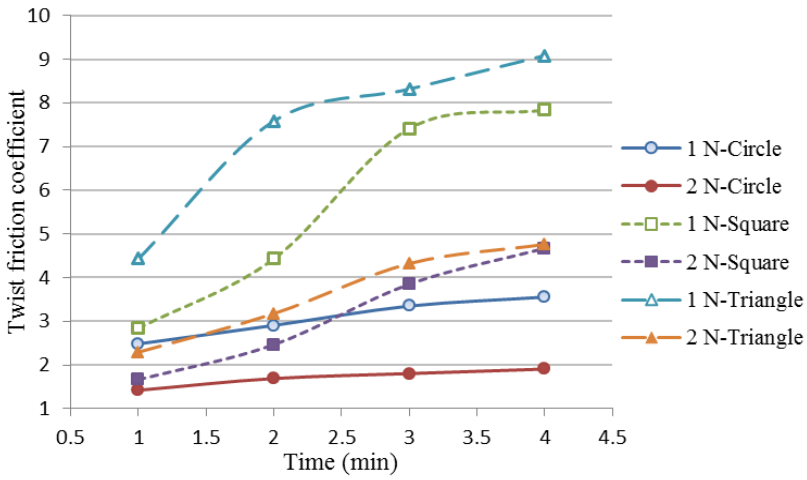

Fig. 4. Variations of twist friction coefficient respect with time.

Creep area. The variation of the creep area experimental data against time for circle, square and triangle shapes at 1 N and 2 N loads is given in Fig. 5. The circle shape produced a maximum creep area of 19.8 mm^2 at load 2 N and time 4 minutes, which is 6.16% and 10.6% higher than that produced by square and triangle shapes respectively, At 1 N load, the circle shape produced a maximum creep area of 19.48 mm^2, which is 7.29% and 11.14% higher than that produced by square and triangle shape respectively. In general, the profile shows that in a shorter time, the circle shape has approximately the same creep area as square and triangle shapes, and then increases when the time increases. This behavior is explained due to creep response of skin, that viscoelastic material when the rectangular step load is applied.

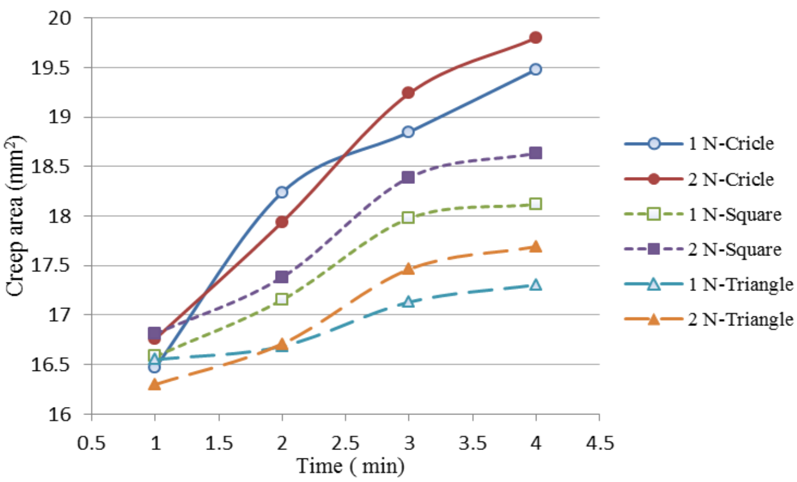

Fig. 5. Variations of creep area respect with time.

Figure 6. present the effect of tips (three types) rotated clockwise direction on cow skin surface during the time (1 to 4 minutes, increment 1 minute). As shown in this figure, the creep area and depth was increased during the time for all the tips. These mechanical properties may be due to viscoelastic and nonlinear of skin.

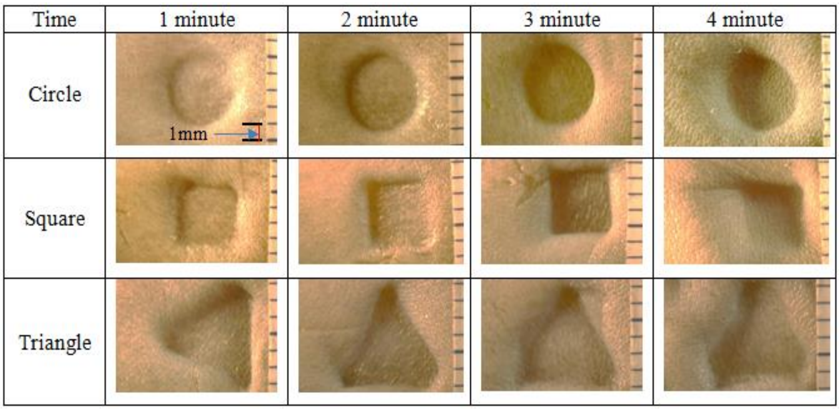

Figure 6. Tip traces in the cow skin for one sample.

These theoretically aspects will be analyzed in the future work for square, circular and triangular shapes of the flat punch for two materials (brass and UHMWPE).

Conclusions

In this experimental study, the viscoelastic behavior of the cow skin and the twist static friction of rigid material (brass) is highlighted.
The viscoelastic behavior of the skin is determined by creep at two constant normal loads (variation of the surface trace after normal force cessation) and for three types of plane surfaces (circle, square, triangle) with the same contact area.
From the results analysis we can draw the following conclusions:
- Cow skin fluctuation creep increases with increasing normal load with a step increase;
- The shape of the flat contact section (circle, square, and triangle) is very important for creep the skin; the greatest creep takes place at the circular surface and the smallest on the triangular surface, regardless of the material of the punch (brass);
- The conventional coefficient of static twist friction depends on the shape section of brass material;
- The static twist friction coefficient increases with the time of the loading period.
- According to the above results of cow skin, we suggested using cow skin as the interior layer and rigid support of above elbow or foot socket, in order to create a mechanical shock absorber (damper) and the minimum friction force.

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