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Frictional Properties of Cartilage loaded against Cartilage by using a Pin on Disc Tribometer

Luigi Lentini[a*]

[a]*Department of Mechanical and Aerospace Engineering, Politecnico di Torino,*
Turin, Corso Duca degli Abruzzi 24, 10129
luigi.lentini@polito.it

Abstract.
Articular cartilage is a specialised, aneural and avascular connective tissue that lines the end of synovial joints. Its main functions are minimising friction and wear during the movements between the joint surfaces, and spreading and transmitting loads and shocks over a larger area within articulations. Many studies have been performed to shed light on the outstanding tribological features of this soft poroelastic material. However, despite the effort expended, many aspects remain unclear. This paper presents an experimental investigation on the effect of the load and static loading time over the frictional properties of adult bovine articular cartilage.

Keywords: articular cartilage, friction, pin-on-disc, loading time.
PACS: 87

INTRODUCTION

Articular cartilage (AC) is a specialised connective tissue which covers the articular ends and bones of synovial joints (SJ). Its main functions are bearing loads transmitted through joints and providing low friction relative motions between articular ends. Nowadays, SJ deterioration is a pathology that impacts on the quality of life of young and old people. It is well-known that this mechanism is strictly related to the status of and the interactions between AC and synovial fluid (SF). For this reason, identifying the properties of AC and SF and understanding how they interact is of utmost importance to provide effective solutions and therapies against SJ deterioration, and tribology has been provided significant experimental and theoretical contributions in this field. Many lubrication theories have been proposed and employed to clarify the lubrication mechanism occurring in diarthrodial joints, e.g., hydrodynamic, elastohydrodynamic (EHL), squeeze film, weeping, boosted and boundary lubrication. However, the whole lubrication mechanism is not completely clear. It has been demonstrated by many investigations [1–3] that the interstitial fluid pressurisation is the main lubrication mechanism regulating the frictional properties of this soft poroelastic material. Although these investigations have confirmed this theory, the measured friction coefficients are quite disparate and only a few of the studies employed cartilage against cartilage configurations.
This paper presents an experimental investigation on the effect of the normal load [3] and the static loading time [2] over the frictional properties of adult bovine AC in a cartilage against cartilage configuration.

MATERIALS AND METHODS

The two cylindrical plugs of AC employed were harvested from the femoral head and the medial condyle of an unknown age adult bovine. The sample from the femoral head and the medial

[*] Corresponding author: luigi.lentini@polito.it

condyle were employed as counterface and pin respectively. The pin was cut by using hole saws with a diameter of 23 and 43 mm. The smaller hole saw was used to obtain the pin, whereas the other was used obtain the counterface. To avoid chemical contamination, the hole saws were washed firstly with ethylic alcohol and secondly with saline solution. Figure 1 and 2 show photographs of the cylindrical plug obtained from the medial condyle before and after being harvested.

Figure 1: Cartilage plug from the medial condyle before being harvested

Figure 2: Cartilage plug from the medial condyle after being harvested

The sectioning was performed through successive steps followed by resting periods in which surfaces were kept cool and hydrated by gently spraying them with saline solution (0,9% Na^{+}). The subchondral bone of each sample was retained (~ 5 mm) to facilitate its handling and fixation.

Figure 3a: Smaller aluminium disk

Figure 3b: Larger aluminium disk

Figure 3c: Aluminum pin

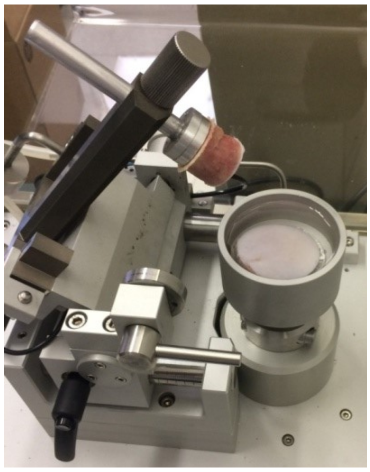

Figure 4: Testing configuration

To reduce measuring errors due to surface inclination, the planarity of the subchondral bone surface of each specimen was cut and verified with the aid of an electrical reciprocating saw and a spirit level. After being harvested, the AC specimens were stored in saline solution at 4°C until tested on a pin on disc tribometer (by Anton Paar). The pin and the disc of the tribometer were suitably modified to allow the integration of the cartilage plugs. Figure 3 and 4 show photographs of the modified pin and disc, and the adopted experimental configuration respectively. The aluminium discs depicted in Figures 3a and 3b were employed as interfaces between the cartilage plugs and the tribometer. The larger and the smaller aluminium disc were fastened onto the rotating bath and the pin of the tribometer with connecting screws, whereas AC plugs were glued to the aluminium discs with cyanoacrylate-base adhesive glue. Frictional tests were performed imposing reciprocating motion on a curve trajectory $l = r\vartheta = 2$ mm with a constant radius r =17.94 mm and a corresponding angle $\vartheta = 6°$, for a duration of $\Delta t_s = 5$ min and 12 s. The sliding velocity U was 2 mm/s for every test. This choice was dictated by the fact that physiological sliding velocities ranging from 1 to 4 mm/s [1]. External normal loads W were imposed by applying dead-weights on the pin arm of the tribometer. While sliding, cartilage samples were completely soaked and lubricated by saline solution (0,9% Na^+). To allow rehydration, after each test the AC samples were immersed in a saline bath for a period T_r, from now on referred to as resting period. These resting periods was defined as equal to the test duration Δt_s (while sliding) plus the static loading time T [2]. Friction coefficients were computed as the mean between the friction coefficients measured in the clockwise and anticlockwise direction by not taking into account the zone where the motion reversed. The first type of tests was aimed to investigate the effect of normal load (W = 8, 16, 30 and 40 N) on the frictional properties of AC. In the second series of tests, the effect of the static loading time (T = 0, 1, 5, 10, 20 and 30 minutes) on the frictional response of articular cartilage was studied.

RESULTS AND DISCUSSIONS

The main goal of this work was to investigate the effect of the normal load W and the static loading time T on the frictional response of AC by adopting a cartilage against cartilage configuration. Figures 5 and 6 shows the results related to the investigation on the effects of the static loading time and the normal load respectively. As can be seen, the AC frictional properties exhibit a time-dependent behaviour [2]. The presence of the interstitial fluid pressurisation is confirmed by the fact that, in each type of test, the measured friction increases as time elapses because of the interstitial fluid exudation. The pressurised interstitial fluid within AC initially supports the most of the applied load through the co-existence of hydrostatic and maybe hydrodynamic lubrication mechanisms. In this way, only a small fraction of the load is supported by the solid phase of the cartilage matrix, thus providing very low friction coefficients. As time elapses, the load sharing gradually transfers to the solid phase due to the fluid exudation from the AC matrix. During this phase, friction coefficients increase because, as the surfaces of the AC specimens approaches one each other, boundary lubrication takes place, gradually becoming predominant. The effect of the interstitial fluid exudation and its consequent depressurisation is clear in Figure 5, where the initial friction coefficient increases with the static loading time T. This behaviour may be due to the characteristic creep exhibited by AC. As the static loading time increases, the pin sinks into the counter surface thus leading to increases of the initial static friction. More specifically, these curves exhibit two different trends. For $T \geq 20$ min, the friction coefficient monotonically decreases up to a steady-state condition, whereas for $T < 20$ min, the friction coefficient decreases up to a minimum and then linearly increase. In the latter case, in the linear region, the slope of the curves decreases as T increases. Figure 6 shows the results related to the tests on the effect of the normal load on the friction coefficient. These curves exhibit very similar shapes and initial friction coefficients. In the absence of static loading time (T =0 min), increasing the normal load W leads to lower friction coefficients. This may ascribed to the fact that higher normal loads flatten the surface asperities, thus reducing friction. The reliability of this findings is also confirm by a past numerical investigation on the load effect on the friction coefficient [3]. This work represents a new research project which is developing at the Department of Mechanical and Aerospace Engineering at Politecnico di Torino [4–6].

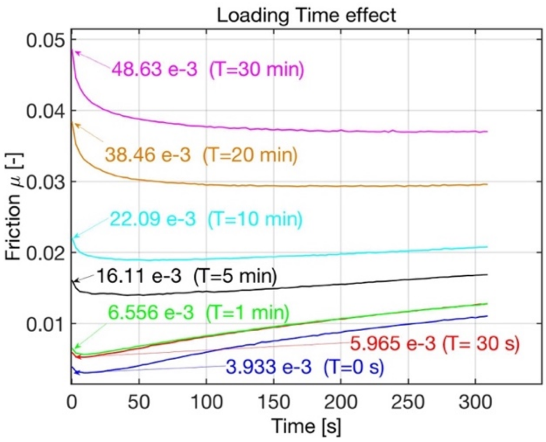

Figure 5: Influence of the loading time

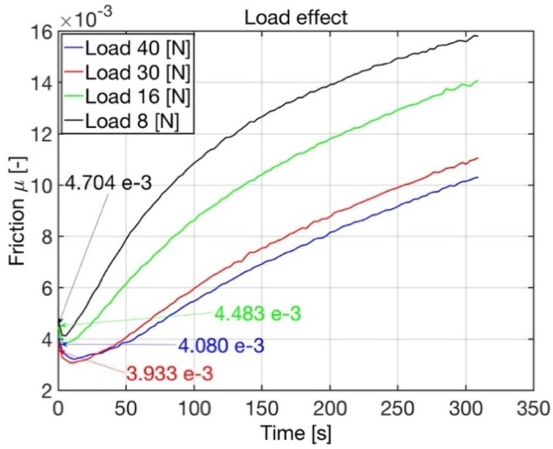

Figure 6: Influence of the normal load

REFERENCES

[1] Katta, J., Jin, Z., Ingham, E., and Fisher, J., 2008, "Biotribology of Articular Cartilage—a Review of the Recent Advances," Medical engineering & physics, **30**(10), pp. 1349–1363.

[2] Forster, H., and Fisher, J., 1996, "The Influence of Loading Time and Lubricant on the Friction of Articular Cartilage," Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, **210**(2), pp. 109–119.

[3] Katta, J., Pawaskar, S. S., Jin, Z. M., Ingham, E., and Fisher, J., 2007, "Effect of Load Variation on the Friction Properties of Articular Cartilage," Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, **221**(3), pp. 175–181.

[4] Belforte, G., Raparelli, T., Viktorov, V., and Trivella, A., 2007, "Permeability and Inertial Coefficients of Porous Media for Air Bearing Feeding Systems," J. Tribol, **129**(4), pp. 705–711.

[5] Belforte, G., Raparelli, T., Viktorov, V., and Trivella, A., 2009, "Metal Woven Wire Cloth Feeding System for Gas Bearings," Tribology International, **42**(4), pp. 600–608.

[6] Belforte, G., Colombo, F., Raparelli, T., Trivella, A., and Viktorov, V., 2010, "Performance of Externally Pressurized Grooved Thrust Bearings," Tribology letters, **37**(3), pp. 553–562.