DOI: 10.31265/atnrs.769

ANNUAL TRANSACTIONS OF THE NORDIC RHEOLOGY SOCIETY, VOL. 32, 2024

Hydrogel-Based Artificial Blood as a Lubricant in Bio-Tribological Model System Testing

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ABSTRACT

Understanding the tribological behavior of blood-lubricated interfaces is considered relevant for the design of heart pumps, heart valves or for the understanding of the blood flow in very narrow blood vessels. Tribological studies with real biological materials are challenging, e.g., due to their limited stability or potential risk of infections. To overcome these challenges, artificial materials are used in this study to mimic real blood and the biological interfaces. As for the lubricant, a hydrogel-based artificial blood with a glycerol-water solution, as a continuous phase, is used. Various compositions of artificial blood are investigated and compared with real plasma as well as platelet-rich plasma as lubricants. Soft biological interfaces are represented by a glass-ball-on-three-elastomeric pins setup.

Results from tribological model system measurements on the different lubricants are shown in the form of Stribeck curves and possible lubricating mechanisms are discussed. Results from complementary shear rheological measurements of the blood fluids are shown and discussed.

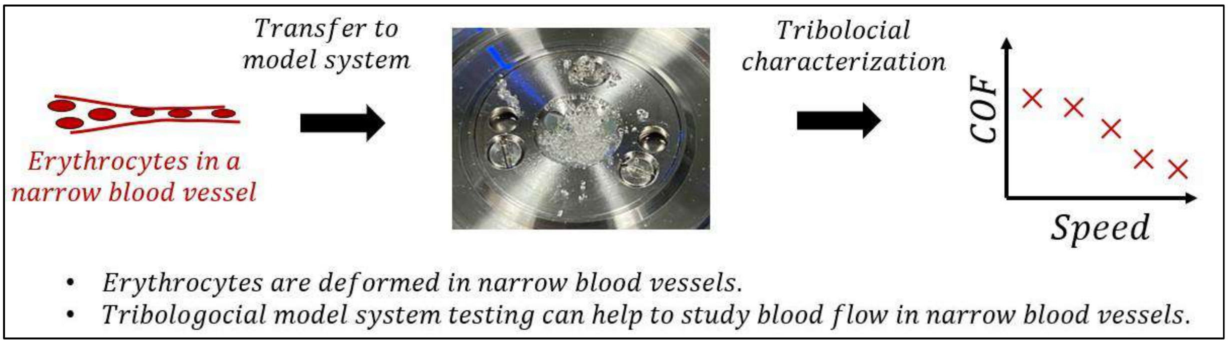

FIGURE 1: Graphical abstract: Erythrocytes in a narrow blood vessel in the real world are represented by hydrogel particles in the artificial blood. The blood vessel walls are represented by soft specimen. The frictional behavior of different blood and artificial blood samples is compared and discussed.

INTRODUCTION

The nature of blood flow (e.g., homogeneous fluid) depends on the blood vessel and the blood cell diameter [1]. The most common blood cells are erythrocytes, which are typically flexible, biconcave discs with 6 - 8 µm in diameter and 2 µm in thickness [2]. Considering that the characteristic diameter of blood capillaries measures 5 - 10 µm and adjoining arterioles and venues have diameters ranging from 10 - 25 µm [3].

The scenario of erythrocyte dimensions being bigger or similar to the blood vessel diameter, makes it interesting to study the tribological behavior of blood-lubricated interfaces. Here, the endothelial surface layer of the blood vessels has to withstand the shear stresses and may protect the cells from mechanical damage [4]. Regarding atherosclerosis with narrowing of the blood vessels and the rubbing contact between blood cells and tissue requires more detailed knowledge about the frictional losses in these contacts. Additional interest can be found in the interaction of valve leaflet and valve ring of artificial heart valves and blood cells [5]. For further optimization of artificial heart pumps and valves as well as stent materials (especially regarding aging and overgrown by tissue of these materials), the tribological interactions have to be understood.

As tribological studies involving real biological materials pose significant challenges, such as those due to their limited stability or potential risk of infections, a model system is introduced in this study to gain insights into the lubricating properties of different blood and artificial blood samples. In this approach, soft biological interfaces are represented by a glass-ball-on-three-elastomeric pins setup. The artificial blood consists of hydrogel-based erythrocytes with a glycerol-water solution as the continuous phase. Different compositions of artificial blood are tested and compared with real plasma in addition to platelet-rich plasma as lubricants.

Results from tribological model system measurements on the different lubricants are shown in the form of Stribeck curves and possible lubricating mechanisms are discussed. Also, complementary shear rheological measurement findings of the blood fluids are illustrated.

MATERIAL AND METHODS

Blood Samples

Beads representing erythrocytes in the artificial blood were obtained via a microfluidics process from agarose and Sodium Acrylate-Acrylamide (pSSAm). The beads were dispersed in a 36%v/v glycerol solution. A 50%v/v glycerol solution was also used as a lubricant and bovine blood samples were used as references materials in this study.

Tribological characterization of blood and artificial blood

The tribological measurements in this study were carried out on a Kinexus Prime rotational rheometer equipped with a Peltier-plate cartridge and a tribology cell (NETZSCH-Gerätebau GmbH, Germany). The ball-on-three-pins setup comprises a borosilicate glass ball with 12.7 mm in diameter and three elastomeric pins made of SIL 30 silicone urethane elastomer (Carbon Inc., USA) as described in [6]. The specimen remained in the sample holder and the measuring geometry shaft throughout the experiment. All measurements were carried out at 25°C. The applied normal force was kept constant at 1 N. Extend Stribeck curve measurements as described in [7] were carried out with an increasing angular velocity from around $1 \cdot 10^{-3}$ rad·s^{-1} to 20 rad·s^{-1}.

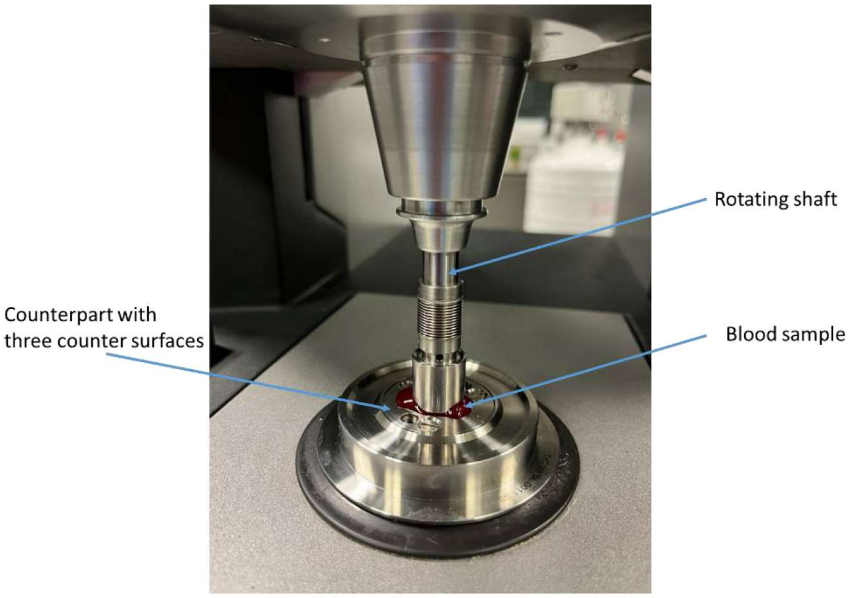

FIGURE 2: Rheometer with tribology cell and blood as lubricant.

RESULTS AND DISCUSSION

The results of the tribological measurements are shown in the form of extended Stribeck curves in Fig. 3. It can be seen that the frictional behavior of platelet-rich plasma and plasma is relatively similar over the entire velocity range, exhibiting two local maxima and the highest coefficient of friction at relatively high velocity (10^0 rad·s^{-1} to 10^1 rad·s^{-1}). In comparison to the reference fluid, the friction could be reduced. It can be assumed that the platelet-rich plasma provides beneficial sliding planes resulting in lower friction as can be seen for 2D materials as grease additive[8]. The limiting friction is highest for the pure glycerol sample, and lowest for the pure hydrogel beads sample. This can be attributed to the friction-reducing effect of hydrogel particles at a soft tribocontact[9].

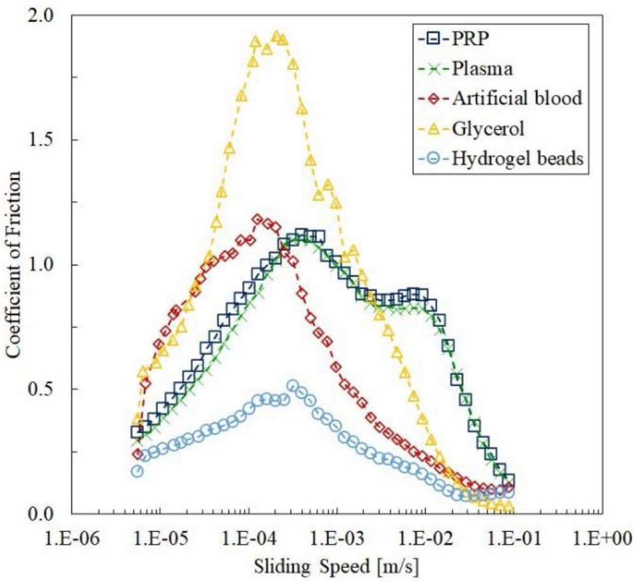

FIGURE 3: Extended Stribeck curves for various blood and artificial blood samples

CONCLUSION AND OUTLOOK

In this study, it has been shown that the frictional behavior of soft model system tribocontacts lubricated with different blood and artificial blood samples can be well differentiated in terms of absolute values and velocity-dependency. It can be concluded, that in the lubrication film between the sliding ball and counter surface, hydrogel particles respective erythrocytes are passing and feature a contacting surface. In comparison to pure glycerol, the friction is reduced by the blood cells as well as by the hydrogel beads. To further understand sliding of the blood cells regarding their sliding planes, and the properties of the soft hydrogels, further studies have to be conducted. To further optimize the experimental approach, the authors intend to further develop the specimens, e.g., with fiber-spun coated surfaces, aiming to better mimic the nature of blood vessels and artificial tissue used as materials for heart pumps and valves. Surface topography, particularly surface roughness, but also deformability are considered particularly relevant parameters for future experimental setups.

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