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Effect of Slide-to-roll Ratio on Film Thickness Formation in Bovine Serum Lubricated Contact

Jan Laštůvka[1], Dalibor Bosák [2], Tomáš Návrat[3] & Martin Vrbka[4]

Abstract: The purpose of this study is to describe the effect of slide-to-roll ratio on the film formation and thickness in artificial CoCrMo metal femoral head and a glass disc contact lubricated with Bovine Serum. The experiment is carried out using an optical testing device and high speed camera capturing chromatic interferograms of the contact zone. The interferograms are evaluated using thin film colorimetric interferometry. The resulting film formation and thickness is studied as a function of time for three different slide-to-roll ratio values. Rolling showed formation of steadily increasing film up to thickness of 23 nm. The sliding test with ball faster than disc did not result in a significant film formation, only a thin film of 2 to 4 nm was formed. The other sliding test with disc faster than ball developed thinner base film of 4 to 20 nm and a thicker protein aggregation film of 60 to 120 nm.

Keywords: Artificial hip joint; Biotribology; Bovine serum; Metal femoral head

1. Introduction

Using of the total hip artrhoplasty (THA) as a treatment method for degenerative, injury related and other diseases of human hip joint results in an estimated 1,000,000 surgeries performed worldwide, and the total number is expected to rise. [1] The THA can significantly improve the quality of patient's life for some 15 to 20 years after the procedure.

There are four criteria vital for the longevity and stability of a prosthesis: material, design, fixation and wear, and among these four the most important today is the rate of wear. It is the formation of wear microparticles in the artificial hip joint that causes osteolysis and aseptic loosening, the main reason for THA failure. Since the production of wear particles is the main issue and its reduction is of great attention, there are efforts to describe the parameters controlling the wear rate. [2]

[1] *Bc. Jan Laštůvka; Institute of Solid Mechanics, Mechatronics and Biomechanics, Faculty of Mechanical Engineering, Brno University of Technology; Technická 2896/2, 616 69 Brno, Czech Republic; y101124@stud.fme.vutbr.cz*
[2] *Bc. Dalibor Bosák; Institute of Machine and Industrial Design, Faculty of Mechanical Engineering, 616 69 Brno University of Technology; Technická 2896/2, 616 69 Brno, Czech Republic; y107116@stud.fme.vutbr.cz*
[3] *Ing. Tomáš Návrat, Ph.D.; Institute of Solid Mechanics, Mechatronics and Biomechanics, Faculty of Mechanical Engineering, Brno University of Technology; Technická 2896/2, 616 69 Brno, Czech Republic; navrat@fme.vutbr.cz*
[4] *Ing. Martin Vrbka, Ph.D.; Institute of Machine and Industrial Design, Faculty of Mechanical Engineering, Brno University of Technology; Technická 2896/2, 616 69 Brno, Czech Republic; vrbka.m@fme.vutbr.cz*

Wear is influenced by the articulating surfaces and not only the biomaterials, hence the wear rate could be reduced by the tribological parameters modification. Among these the key one is the lubrication regime having direct influence on the friction coefficient. Bovine serum (BS) is used nowadays as a model synovial fluid lubricant for modelling the wear and friction properties of artificial joints. The artificial joint articulation is simulated using simple ball-on-disc configuration of the artificial (metal or ceramic) femoral head and a glass disc.

This paper should add information to the research findings presented in the current studies specializing on experimental analysis of lubricating film thickness in the contact zone. This is the reason for the aim of the study, which is to describe the effect of slide-to-roll ratio on the film formation and thickness in metal femoral head and glass disc contact.

2. Experimental method

The film thickness measurements were performed using an optical testing device (Fig. 1), where a round contact was formed between a glass disc and the artificial metal femoral head of total hip joint replacement and was monitored by a high speed camera. A 12 ml volume of BS (Sigma-Aldrich B9433, protein concentration 75.3 mg/ml) blended with distilled water to 25% w/w concentration was used for lubricating the articulating surfaces. The lower side of the glass disc was coated with a thin chromium layer and the upper side had an antireflective coating. The artificial femoral head AESCULAP NK430K forged from CoCrMo alloy was 28 mm in diameter and was delivered in original packaging from the manufacturer. The room temperature as well as the BS temperature during the test was 24°C.

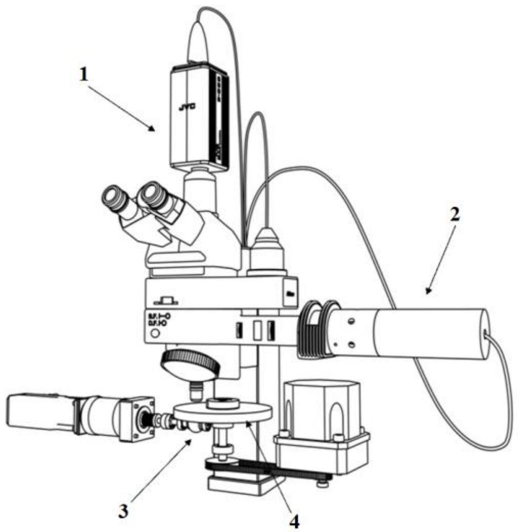


Fig. 1. Testing device used for measurements [3], 1 – high speed camera, 2 – halogen lamp, 3 – metal femoral head, 4 – glass disc.

The metal head and disc were rotated using servomotors at a stable speed. Ball speed u_B and disc speed u_D were controlled to maintain constant kinematic conditions in the contact. A slide-to-roll ratio $\Sigma = 2(u_D - u_B)/(u_D + u_B)$ was used to describe the three different investigated kinematic conditions. These were $\Sigma = 0$ (pure rolling), $\Sigma = -1.5$ (ball faster than disc sliding) and $\Sigma = 1.5$ (disc faster than ball sliding). Table 1 shows the ball and disc surface speeds used, which provided constant mean surface velocity $u_M = (u_D + u_B)/2$.

Table 1. Ball and disc speeds

Σ	u_D [mm/s]	u_B [mm/s]	u_M [mm/s]
0.0	5.7	5.7	5.7
–1.5	1.4	10.0	5.7
1.5	10.0	1.4	5.7

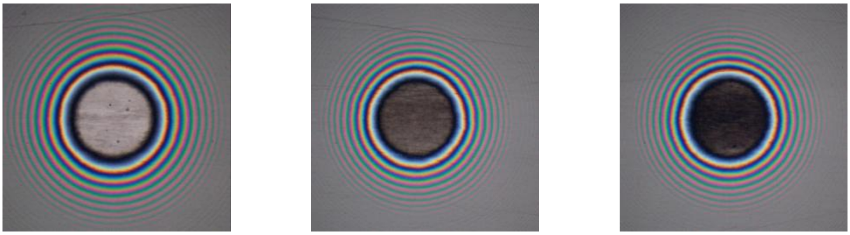
The duration of the one test was 300 seconds, while for the first 180 seconds the BS was supplied using a syringe attached to a linear motor to maintain constant volume rate and a needle fixed in place using a clamp. A volume rate of 3.5 ml/min ensured sufficient lubrication of the contact with the BS flowing directly onto the metal femoral head. The tests were performed under a steady state load of 5 N, which corresponds to mean Hertzian pressure of 180 MPa. All components in contact with BS were cleaned carefully before each test.

The contact zone between the glass disc and the metal femoral head was illuminated using a halogen lamp and the resulting chromatic interferograms were taken at 24 Hz sample rate and 800x600 pixels resolution with a high-speed camera. The direction of the rotation and BS flow was from left (inlet zone) to right. A total of 7200 interferograms were captured over the 300 seconds for every of the three tests, of which several interferograms representative of the film behaviour were selected at a constant time interval of 15 seconds. This produced 21 interferograms, which were evaluated using thin film colorimetric interferometry to provide information on film thickness and its distribution in the contact zone.

3. Results and discussion

The film thickness was studied as a function of time for the three different kinematic conditions. During the tests, the BS was passing through the contact zone, and 21 interferograms were selected and evaluated. For every interferogram, the average film thickness value in the central area was plotted in a graph to show the time progress. The graphs and interferograms describing the development of the film for the three tests are shown in Figs. 2-4. The time-thickness diagrams show the formation of lubricating film over a period of 300 seconds, while the selected interferograms show the behaviour typical for the slide-to-roll ratio conditions

The first case of pure rolling ($\Sigma = 0$) shows a steadily increasing lubricating film which reaches a thickness of 23 nm at the end of the measurement. The thickness distribution in the contact zone is uniform and does not show any noticeable signs of protein aggregations. This shows that only the base film contributes to the total film thickness.



time = 0 seconds **time = 150 seconds** **time = 300 seconds**

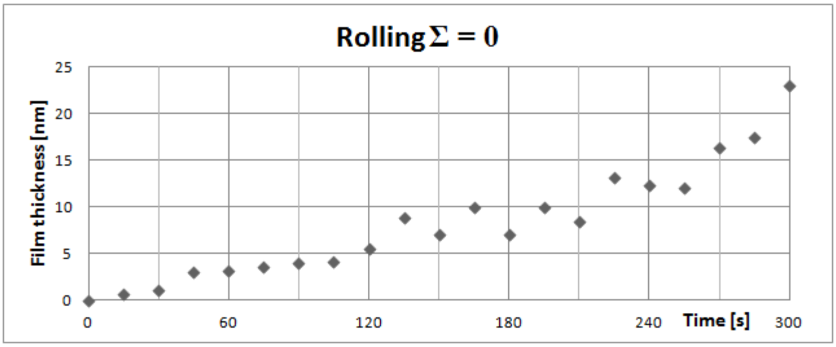
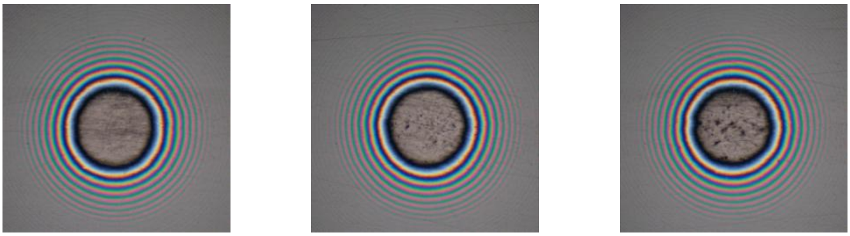


Fig. 2. Interferograms and time-thickness graph for pure rolling (Σ = 0).

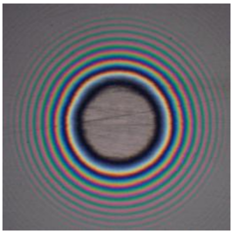
The second case of Σ = –1.5 shows formation of thin lubricating film, with thickness about 2 to 4 nm during the whole measurement, only seldom increased by small protein aggregations of thickness about 10 nm. The interferograms show a contact zone with very thin base film and randomly scattered dots of protein aggregations. Since the behaviour of the lubricating film was very similar during the measurement, time-thickness graph is not important in this case. This test does not provide conditions for the formation of a thicker lubricating film, as the interferograms lack any indication of film thickness increase.



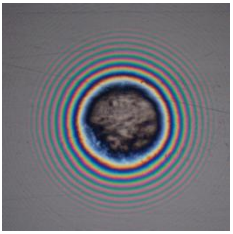
time = 0 seconds **time = 150 seconds** **time = 300 seconds**

Fig. 3. Interferograms for Σ = –1.5.

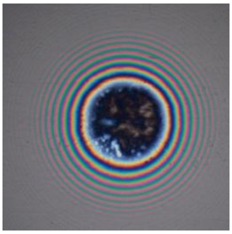
The last case of Σ = 1.5 shows different behaviour, as we can see a formation of thicker aggregated protein regions passing through the thinner base film. The thicker protein film reaches thickness of 60 to 120 nm, whereas the base film varies slightly with thickness of 4 to 20 nm. The interferograms show large areas of aggregated proteins over the thin base film running through the contact zone without any significant time dependence. The results obtained from this test are in agreement with those of Myant et al. [4], who presented that BS film thickness increases for the test and also supported the idea of inlet protein aggregation and forming of a much thicker lubricating film than expected.



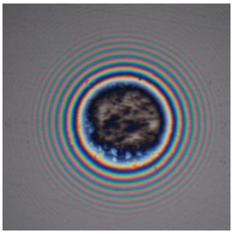
time = 0 seconds



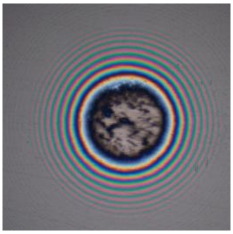
time = 60 seconds



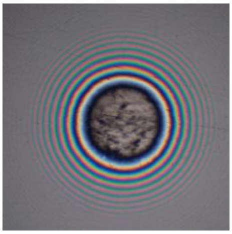
time = 120 seconds



time = 180 seconds



time = 240 seconds



time = 300 seconds

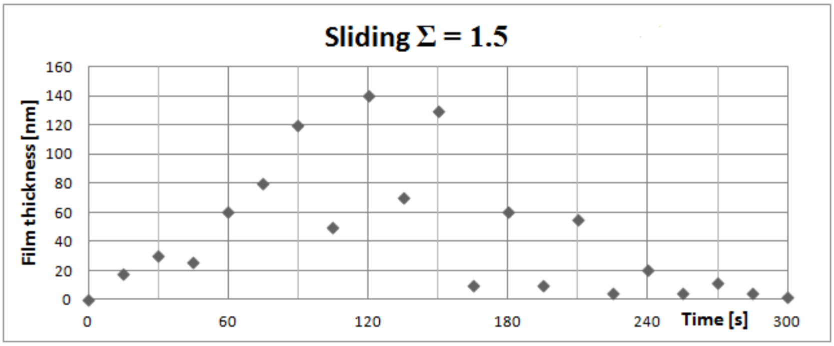


Fig. 4. Interferograms and time-thickness graph for Σ = 1.5.

4. Conclusion

In conclusion, the study confirmed the fact that proteins formation has a significant impact on the lubrication of artificial joints in humans. Due to this fact, a more complex program of experiments is to be carried out in the near future, to describe the film formation in ceramic head contact for the same slide-to-roll conditions and also to study the effect of temperature and different slide-to-roll conditions.

Acknowledgements

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