Effect of Contact Condition on Film Thickness Formation in Artificial Joints

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Abstract. Total hip replacement is the most effective method for treating severe degenerative, post-traumatic and other diseases of the hip joint. Nevertheless wear of artificial implants remains a serious health issue especially for metal-on-metal hip components where the formation of metallic wear debris has been linked to adverse tissue necrosis and increased of metal ions in the blood. Wear in MOM joints is essentially dependent on interfacial lubrication processes, which are subjected to the complex research work at the present time. The aim of this study is to analyze formation of lubrication film and experimental mapping of the lubricating film thickness of bovine serum within the contact between an artificial metal or ceramic femoral head and a glass disc and analyze effect of proteins on the film formation under rolling/sliding conditions. The film thickness was studied experimentally using film colorimetric interferometry. This study showed that protein formation plays an important role in the lubrication processes of artificial joints of the human. Due to challenging of this study the more complex research work is carried out at the present time.

1 Introduction

Total hip arthoplasty (THA) is the most effective method for treating severe degenerative, post-traumatic and other diseases of the hip joint. It is estimated that more than 1,000,000 THAs are performed each year globally. More importantly, modelled future projections expect further increase in the need for THAs [1]. The main reason for late failure of THA is aseptic loosening [2] followed by instability of the THA that compromises predominantly the early postoperative period [3].

Wear is influenced by the articulating surfaces and not only the biomaterials [4, 5], 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

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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 [6] and a glass disc.

This paper should contribute to amend of research findings presented in the current studies that are mainly focused on experimental analyses of central film thickness in the contact zone. That is why the aim of this study is to perform detail experimental mapping of lubricating film thickness of BS within a whole contact zone between artificial metal or ceramic femoral head and glass disc and analyzed effect of proteins on film formation.

2 Methods

Mapping of lubricating film of several BS concentrations was observed using an optical test rig in which a circular contact is formed between a glass disc and a metal or ceramic head of total hip joint replacement. BS (Sigma-Aldrich B9433, protein concentration 75.3 mg/ml) and sterile water were used for preparing samples with appropriate w/w concentrations.

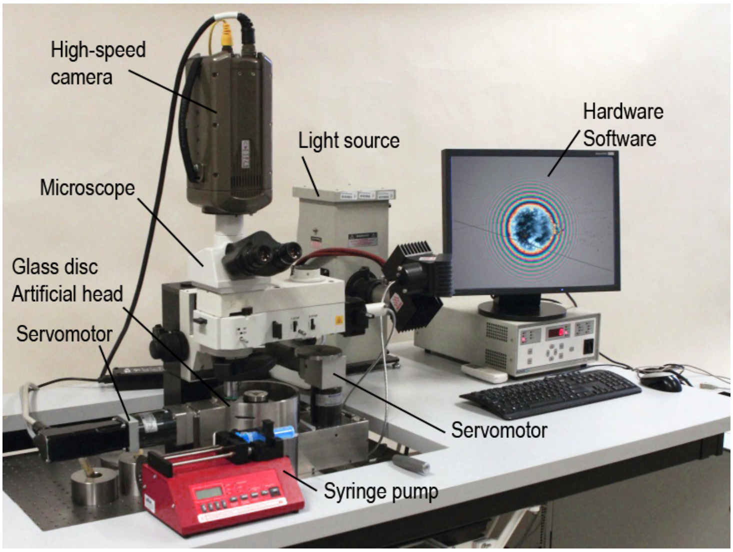

Fig. 1 Optical test rig for lubricant film thickness measurements

Mapping of lubricating film of BS solution was observed using an optical test rig (Fig. 1) in which a circular contact is formed between a glass disc and a metal head of total hip joint replacement (Fig. 2). The artificial heads were rotated by servomotor against the disc to provide pure rolling and sliding conditions.

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 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 clamp. Experiments were realized at room temperature of 24 °C under steady state load of 5 N corresponding to mean Hertzian pressure of 180 MPa for metal head. The contact formed between the glass disc and the artificial heads was illuminated by xenon or halogen lamp. Obtained chromatic interferograms were recorded with a high-speed digital camera (CMOS or 3CCD) and evaluated with thin film colorimetric interferometry. Detailed description of this technique is given in [8, 9]. The chromatic interferograms were taken at 24 Hz sample rate and 800x600 pixels resolution.

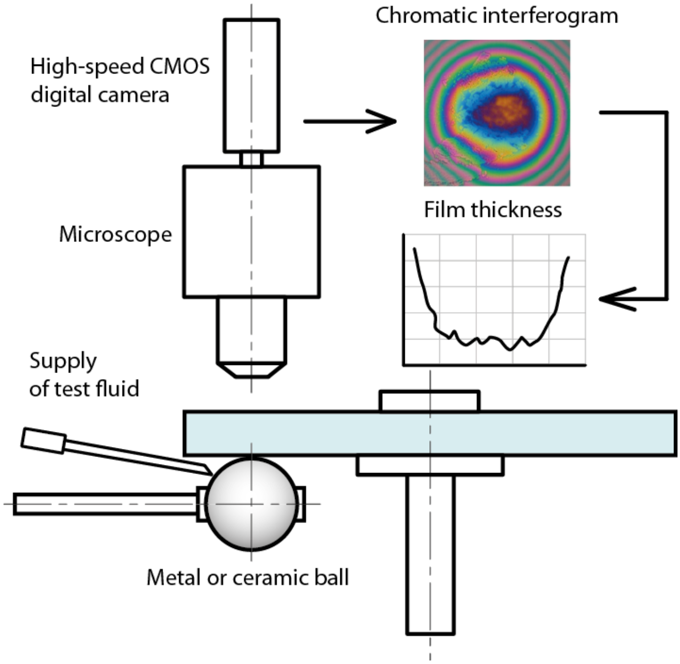

Fig. 2 Schematic diagram of film thickness mapping

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 describing the development of the film for the tests are shown in Figs. 3 and 4. The time-thickness diagrams show the formation of lubricating film over a period of 300 seconds for different slide-to-roll ratio conditions.

The first case of pure rolling (Fig. 3) 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.

The second case of (slide-to-roll ratio is -1.5, the head is faster than the disc) 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.

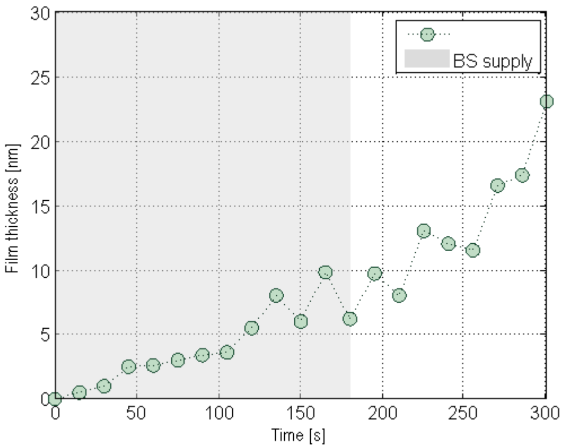

Fig. 3 Central film thicknesses plotted as a function of time for slide-to-roll ratio 0

The last case of (slide-to-roll ratio is 1.5, the disc is faster than the ball, Fig. 4) shows different behavior, 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. [7], 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.

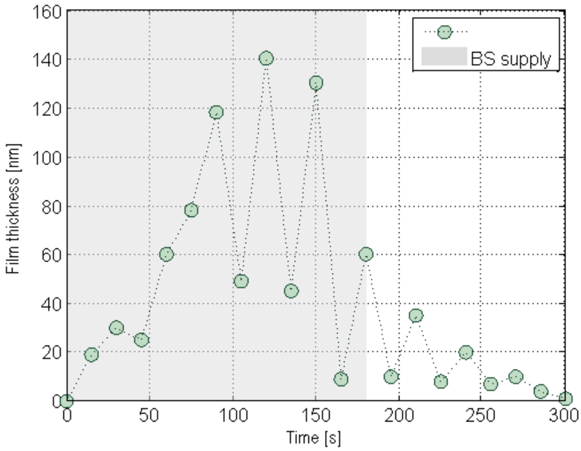

Fig. 4 Central film thicknesses plotted as a function of time for slide-to-roll ratio 1.5

4 Conclusions

Film formation between the artificial metal femoral head and the glass disc was observed using BS as a lubricant. Film thickness measurements were performed as a function of time under pure rolling and rolling/sliding conditions. It is obvious from performed experiments that formation of lubricant film thickness is markedly dependent on the kinematic conditions acting in the contact. 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.

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