THE LUBRICATION IN HIP JOINT

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Abstract: *The theory to the lubrication of diarthrodial joints that contains as well the hip joint was described in the previous articles [4], [5], [6], [7]. In this article, we would like to deal with the simulation and possible simplification of fluid flow in the gap of hip joint.*

Keywords*: lubrication, hip joint, ANSYS FLUENT*

1. Introduction

The lubrication in the hip joint depends on the properties of liquid used for it. In the human body we could find as the lubricant hyaluronic acid in the liquid called synovial fluid. The properties of this fluid depends on the shear rate and film thickness. The type of the lubrication is determined by Stribeck curve.

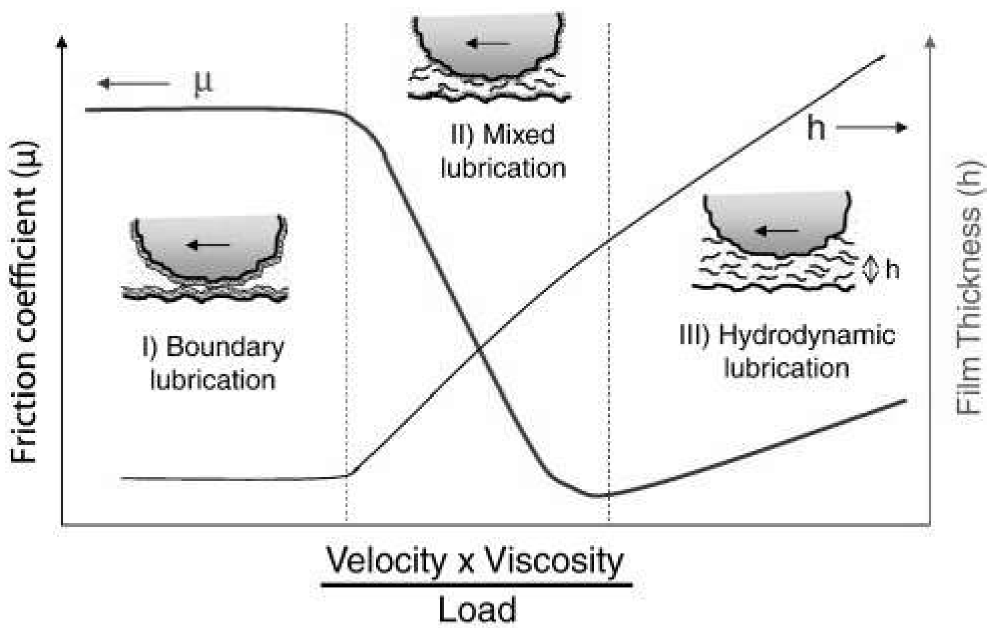


Fig. 1 Stribeck´s curve [1]

The synovial fluid behaves as Non-Newtonian fluid, however under the value 10^{-1} s^{-1} and up from the value 10^{5} s^{-1}, we suppose the synovial fluid as Newtonian fluid.

The properties of synovial fluid could be summarized as followed in the table 1.

	Synovial fluid
Density	*1010 kg/m^3*
Dynamic viscosity	*0.01-10^2 Pas*
Average shear rate	*0.2-1.4 s^{-1}*
Depends on	*Shear rate*
Does nor depends on	*Temperature, pressure*
Concentration of the hyaluronic acid	*0 – 15 mg/mL*

Table 1. Physical properties of synovial fluid

2. Analysis of synovial fluid flow

The 3D model of hip joint is reffered to the ball and socket joint, from what comes the prediction for the symmetricity of the analysis. Our predictions confirms Wierzcholski [2], according to whom the loading of the hip joint could be simplified into the two main directions. These directions are meridial and circumferetial direction as is shown in the picture.

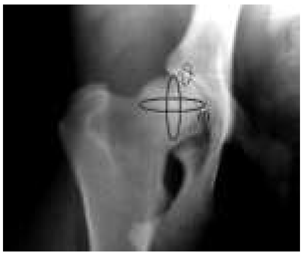


Fig.2 Two main load direction in the hip joint

The area of pressure and lubrication distribution and so the boundary conditions are [2]:

- in the circumferential direction is spread in the upper half of the whole circuit,
- in the meridial direction approximately 22 ° from the upper pole of the head of hip joint.

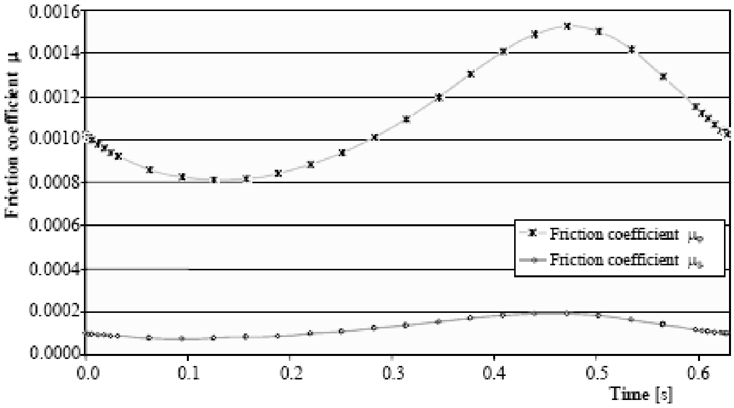
The area of pressure and lubrication distribution could be expressed as:

$$0 \le \varphi \le 2\pi\theta, 0 \prec \theta \prec 1 \quad (15)$$

$$\pi R_1 / 8 \le \vartheta \le \pi R_1, 0 \le h_x \le h \quad (16)$$

where h - the height of the gap,
h_x - the instantaneous height,
R_1 - diameter of the head.

The result of the analysis is the following graph of the coefficient of the friction in the meridial and circumferential direction of the head of hip joint with respect to the time.



Graph 1 The dependence of coefficient of friction of healthy joint in circumferential φ and meridial ϑ *direction with respect to time [2]*

According to these conclusion in the following analysis we would concern on the analysis in the meridial direction as the highest values of coefficient of friction are determined in this direction.

2. Simulation of synovial fluid flow

First of all we had to make the appropriate mesh that would be used for analysis. The mesh was done in the GAMBIT. The size of the head 32 mm was selected from size catalogue of producer of endoprosthesis company BEZNOSKA. The 2D model of the gap would have shape of semi-circle with inner diameter16mm and thickness 50 μm. The mesh was done from 25210 QUAD elements type MAP with size10 μm. The mesh was controlled by the value of the maximum distortion of the mesh that was almost zero and so the mesh was suitable for the computation.

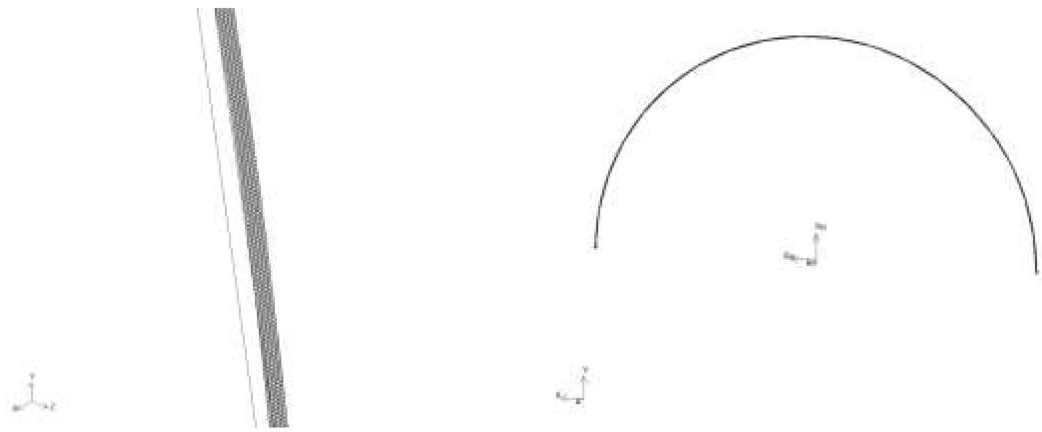


Fig.3 Mesh of the hip joint gap

Simulation were done in the programme ANSYS FLUENT using the standard k-epsilon model. The boundary conditions were:

1. zero pressure in the inlet and outlet
2. the velocity of the outer wall (wall in neighbor with socket of the joint) is zero
3. the velocity of the inner wall (wall in neighbor with head of the joint) depends on the viscosity
4. viscosity is derived from the dependence on the shear rate according to the fig.4

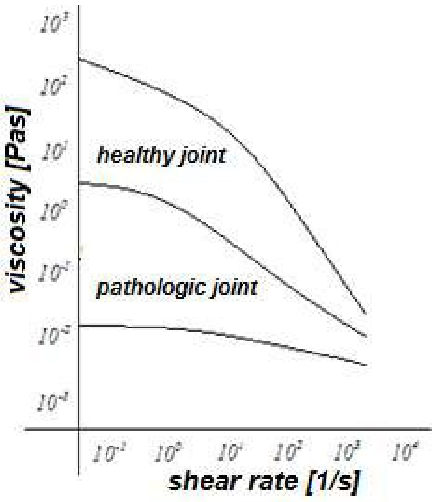


Fig. 4 Dynamic viscosity of healthy and pathologic joint [3]

2D flow in the gap of hip joint

In the following figures you could observe the results from the analysis of fluid flow in the gap of hip joint. Figures 5 and 6 represents very slow flow 10^{-1} s^{-1} , what means that synovial fluid behaves is Newtonian fluid and the viscosity is constant with value 10^2 Pas.

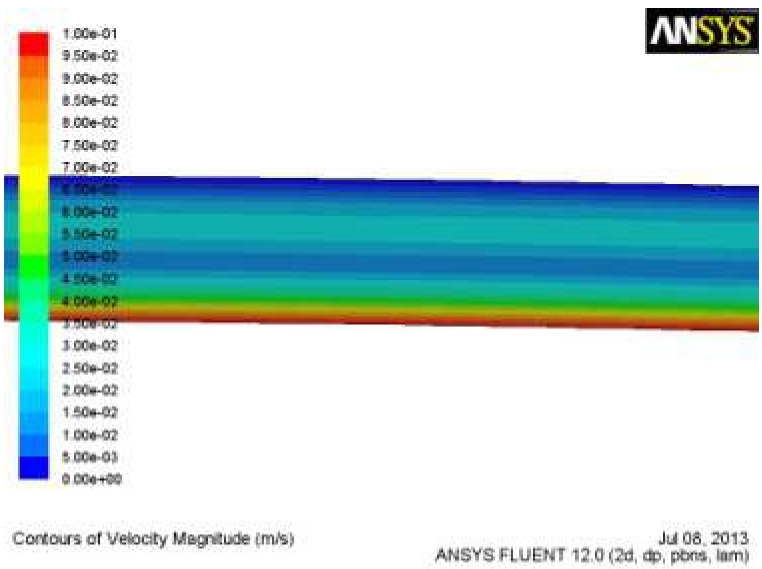


Fig. 5 Result of the simulation of fluid flow during shear rate 10^{-1} s^{-1}

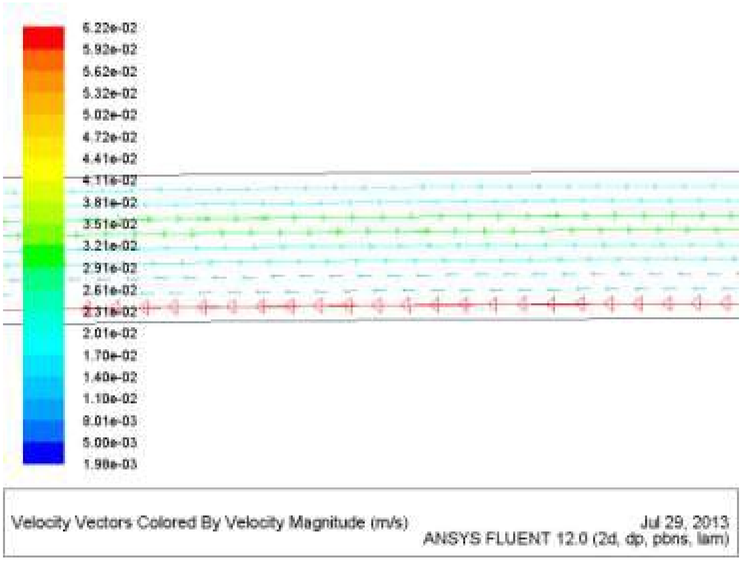


Fig. 6 Result of the simulation of fluid flow during shear rate 10^{-1} s^{-1}*- vectors*

The next analysis was done with the higher shear rate 10^0 s^{-1}. This value means that synovial fluid is not any more in validity of Newtonian laws and so we have to determine in the analysis fluid as Non-Newtonian. The viscosity is determined according to the coefficient K, so called consistency coefficient that is derived from the average value of viscosity and according to the index N, depending on the type of the fluid. In our case it is pseudoplastic fluid. The results of the analysis are shown in figures 7 and 8.

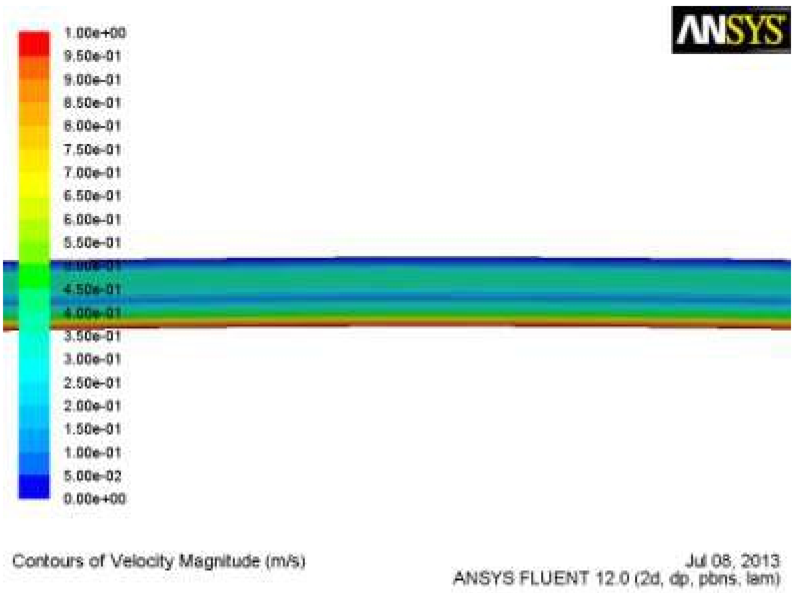


Fig. 7 Result of the simulation of fluid flow during shear rate 10^0 s^{-1}

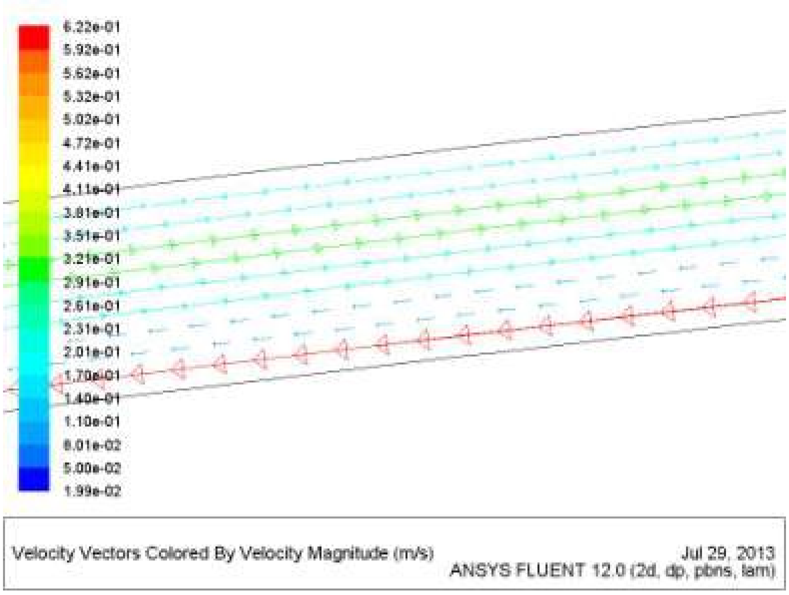


Fig. 8 Result of the simulation of fluid flow during shear rate 10^0 s^{-1} *- vectors*

3. Conclusions

This article was concerned about the analysis of lubrication of synovial fluid in the gap of the hip joint. Before the analysis we found out that the 3D model is not necessary as the effect of the loading is mainly presented in two main directions. Moreover during walking the coefficient of friction is mostly concentrated in the meridial direction. According to this we had analysed the fluid flow in 2D model of hip joint gap in meridial cut. From the analysis follows that although in high velocities, there is a permanent 2-3 µm thick layer of fluid with zero velocity that secures the permanent lubrication layer. This result would be used in the research of the new types of endoprosthesis, in respect with the aim of prolongation of lifetime of endoprosthesis.

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