NUMERICAL MODELLING OF THE OPENING PROCESS OF THE THREE-COATING AORTIC VALVE

M. Kopernik and J. Nowak
Akademia Górniczo-Hutnicza, Kraków, Poland

1. Introduction

The natural aortic valve, which is composed of three leaflets, works under the highest pressure in the circulatory system. In the case of irreversible failure, the valve is replaced with prosthesis. The tendency to create the mechanical valves, whose geometry is based on the real valves, is observed. These artificial organs are made of polyurethane (PU) and covered by TiN coatings to increase the biocompatibility. Development of the mathematical model of the TiN/PU/TiN aortic valve, which is connected with the earlier results obtained in [1] and based on physical formulas derived in paper [2], is the objective of the present work. Analysis of the sensitivity coefficients [1] calculated for the control parameters of the valve opening decided about the assumptions introduced in the new finite element (FE) model. The previous work [1] was dedicated to pure PU aortic valve. Since each of the identical leaflets of the real aortic valve has a three-coating structure, extending the analysis to structure is another objective of this project. The new model satisfies the basic conditions required for the mechanical construction of the aortic valve. The valve opening is used to determine the acceptable values of Young modulus and the thicknesses of outer coatings.

2. The FE model of TiN/PU/TiN aortic valve

The minimal buckling pressure is the basic parameter, which decides about the proper work of the aortic valve. According to Reul [2], this parameter depends on Young's modulus E, thickness of the leaflet d and aortic radius R. The conclusions of the sensitivity analysis for the pure PU aortic valve led to the new set of parameters of the model of the aortic valve (R = 7 mm, d = 0.1 mm and E = 10 MPa) [1], which gives the minimal value of the buckling pressure. In the present work this new construction of the valve has been tested for the three ratios between the thickness of the deposited outer coating and the thickness of the whole leaflet (1:100, 2:100 and 3:100). A search for the best value of the Young's modulus of the outer coating, which provides the minimal buckling pressure, was performed for each ratio. The buckling pressure, which is the loading of the leaflet and is a constant input parameter of the FE model in the present analysis, was taken 0.77 kPa and calculated for the pure PU leaflet with the optimal dimensions given above. The displacement of the TiN/PU/TiN leaflet reached in its characteristic point (Fig. 1a) is the output parameter of the model. The range of this displacement, which is assumed as proper and optimal, is 80-100% of that displacement for the pure PU leaflet. This defined range of the displacements is necessary to obtain the opening of the aortic valve.

3. Results and conclusions

The FE model of three-coating leaflet of aortic valve is generated in the ADINA FE code and is composed of 100 000 elements and 40 000 nodes, as it is shown in Fig. 1a. The displacements in the characteristic point of the leaflet for the valve opening are shown in Fig. 1b for the selected elastic moduli of outer coating and the geometrical ratio 1:100. The thicker is the outer coating and the bigger is Young's modulus, the smaller is the valve opening.

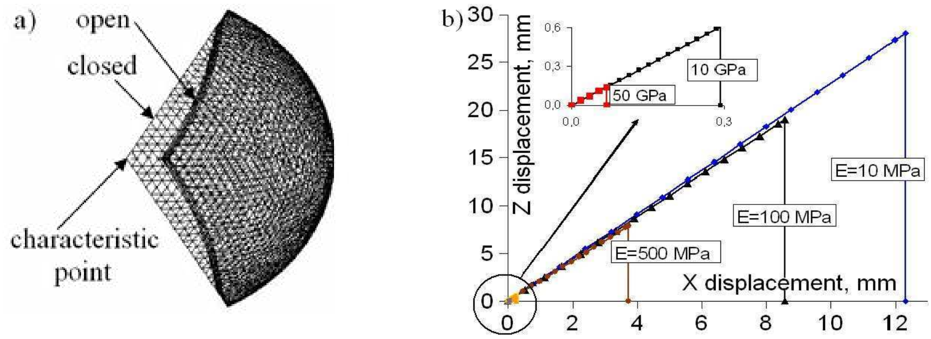

Fig.1. a) The FE model of three-coating leaflet of aortic valve in open and closed positions (top view), b) The valve opening for the selected elastic moduli and geometrical ratio 1:100.

Assuming the opening as the output of the FE model, the sensitivity coefficients of this parameter with respect to the Young's modulus of outer coating are calculated and plotted in Fig. 2a. Following these results, further calculations are dedicated to the remaining geometrical ratios (2:100, 3:100) and, especially to these elastic moduli, which have the meaningful values of sensitivity coefficients for the geometrical ratio 1:100. The valve opening for the set of elastic moduli and ratios (1:100, 2:100 and 3:100) is shown in Fig. 2b.

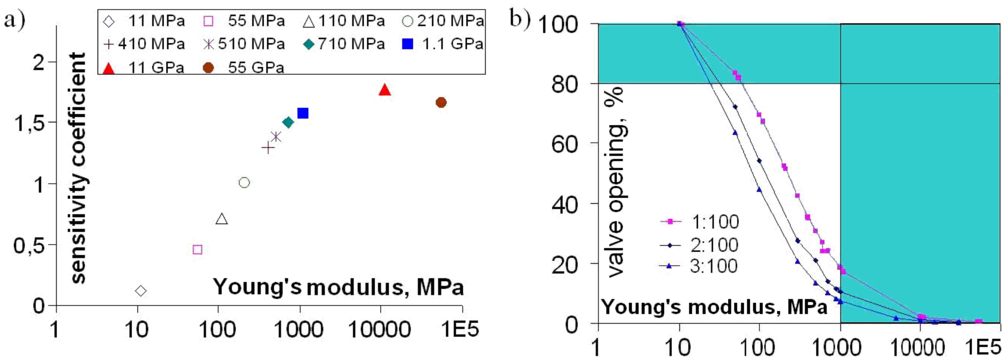

Fig.2. a) The sensitivity coefficients with respect to Young's modulus for geometrical ratio 1:100, b) The valve opening as function of the Young's modulus for all geometrical ratios.

Suggested approach is used to design the optimal values of elastic parameters and thicknesses of outer TiN coating of aortic valve using commercial FE code. The solution fulfills the conditions required for the analysed biomedical part.

4. References

[1] M. Kopernik, D. Szeliga, J. Nowak (2007). Modelling of mechanical response of leaflet of aortic valve based on the sensitivity analysis of geometry and material parameters, *Proc. XVIIth Conf. CMM*, Łódź-Spała, CD ROM, 1-5.

[2] D.N. Ghista, H. Reul (1983). Prosthetic aortic leaflet valve design: performance analysis of Avcothane leaflet valve, *Advance Cardiovascular Physiology*, **5**, 31-42.

Financial assistance of the MNiSzW, project no. N507 136 32/3962, is acknowledged.