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REMAINING LIFE OF TI-6AL-4V ELI HIP IMPLANT WITH A CRACK

Abstract. Fatigue failure is the main issue in design of hip implants. One way to prolong fatigue life is to use newly developed Ti6Al4V Extra Low Interstitials (ELI) alloy. As the most critical part, hip neck has been in the focus of this analysis, keeping in mind that the lower the thickness is, the higher the movement of joint may be, but reducing remaining life of implants with a crack at the same time. In this research extended Finite Element Method (xFEM) is used to analyse this effect.

Introduction.

Extensive research has been performed in recent years to assess fatigue life of hip implants, [1-3] in order to explain failures and then to prevent them. The main issue is fatigue crack growth, related to amplitude loading, e.g. simple walking or running, [2-3]. Different methods have been used to analyze fatigue crack growth in hip implants, including advanced numerical simulation, like xFEM, [2-3]. They all contributed also to better understanding of hip implant design aspects, as shown in more details in [4], where static loading was taken into account. In this paper we focus analysis to amplitude loading, i.e. fatigue crack growth, using total hip replacement implant made of Ti-6Al-4V ELI by precision casting method. All basic data is already given in [4], so here we shortly describe most important results.

Fatigue crack growth – xFEM analysis

Fatigue crack growth has been simulated by using XFEM. Amplitude loading was 3 kN, according to recommended values for normal walking load on hip joint for a person of 90 kg. Normal walking condition is the most suitable for numerical simulation of dynamic loading for regular multiyear exploitation of the total hip replacement implant. Boundary conditions include fixed support on stem surfaces that are facing the inner bone, and fixed vertical movement and rotations around both horizontal axes on bottom surface of the implant collar. Defined boundary conditions are the same as in previous research, [4]. Advanced new alloy based on Titanium, Ti-6Al-4V Extra Low Interstitials (ELI), produced by precision casting method, is used recently to prolong fatigue life, providing the following material properties: $R_{p0.2}$=881 MPa, R_m=971 MPa, K_{Ic}=2100 MPa$\sqrt{\text{mm}}$, coefficients in Paris equation n=2.2, C=$6.72\cdot10^{-13}$. Modulus of elasticity was set at 120 GPa and Poisson coefficient 0.3.

The xFEM model with boundary conditions, loading and geometry is shown in Fig. 1a, whereas the initial crack length (1 mm), positioned at the site of the highest stress states, is shown in Fig. 1b. Ratio between minimal and maximal load was R=0, i.e. the numerical model after applied load is unloaded, like in a walking cycle. The xFEM analysis is performed in software package Ansys 2019R2 (Ansys Inc., Canonsburg, PA).

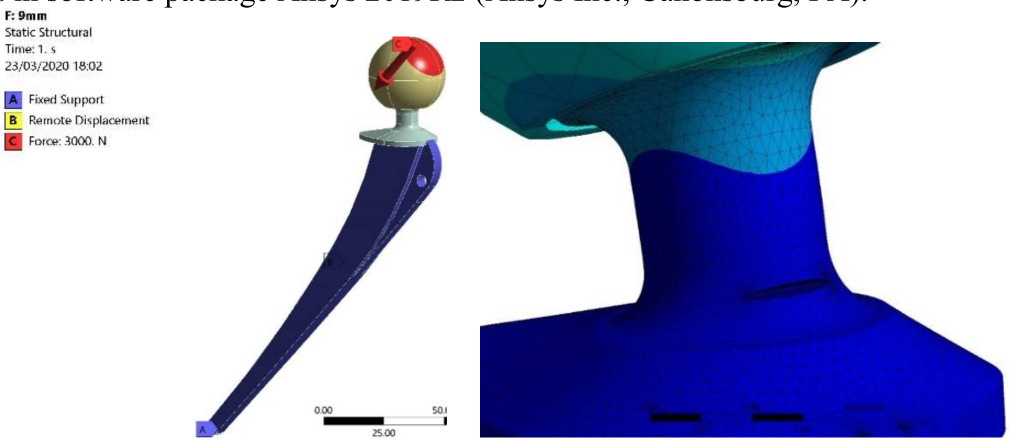

Figure 1. left) Numerical model for XFEM, right) Crack location

Two total hip replacement numerical models, with different neck diameters, 14.6 mm and 9 mm, were taken into consideration for the xFEM. The first one is the originally 3D scanned model, whereas the second one has the recommended neck thickness for the best angle movement, [4]. Stress distributions during fatigue crack growth in these two implants are shown in Fig. 2, indicating the highest stresses in the vicinity of crack front.

Crack length vs. number of walking cycles is shown in Fig. 3, indicating that the implant with 14.6 mm neck diameter can withstand 4.2 million cycles before reaching 4.87 mm (one third of diameter, taken as the critical value), whereas only 1.45 million cycles were enough to reach crack length 3 mm in the case of the implant with 9 mm neck diameter.

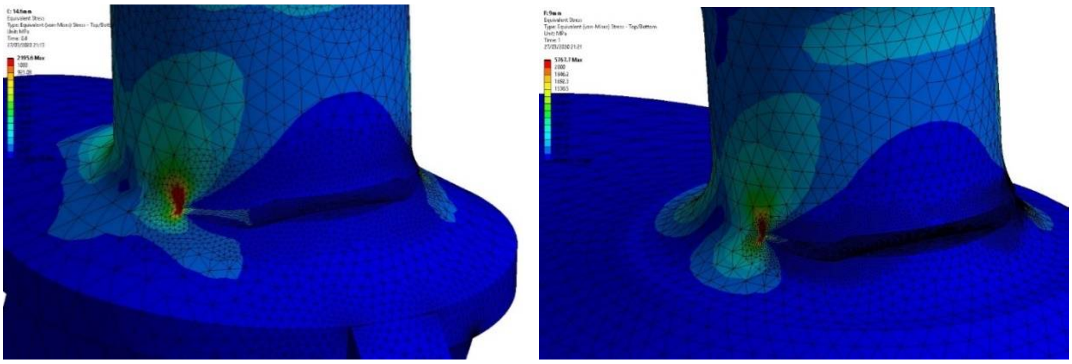

Figure 2. Stress distribution - fatigue crack growth in hip implant with neck diameter (left) 14.6 mm (right) 9 mm

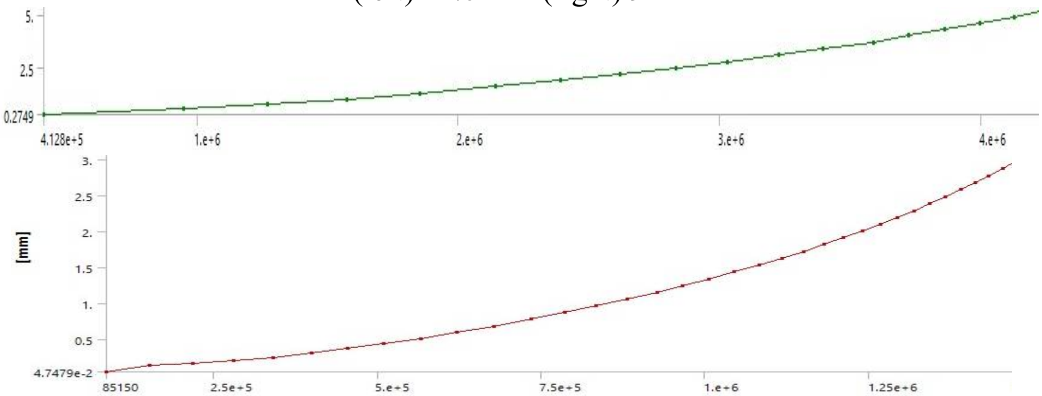

Figure 3. Crack length vs. number of cycles (upper -14.6 mm diameter, lower - 9 mm diameter)

Conclusions. Based on results presented here, one can conclude that the reduction in implant neck thickness from original 14.6 mm to 9 mm, reduces remaining life 3.3 times (from 4.2 million cycles to 1.56 million) in the case of fatigue crack growth from the initial 1 mm to the critical crack length. Such a data is of utmost importance for designers if they try to reduce thickness and improve movement capabilities of a patient. It is not very likely that such a reduction will be accepted, but most probably one can find an optimum thickness value in between 14.6 mm and 9 mm.

References.

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