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Numerical simulation of fatigue crack paths in orthopedic plates

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Abstract

This study is aimed to explain the behaviour of different orthopedic plate designs, under uniaxial bending, with cracks initiated in the stress concentration areas. Extended finite element method (XFEM) in ANSYS software was used for simulating the fatigue crack growth in 5 orthopedic plates with different geometries. Results for crack length vs, plate geometry indicated plate D as the best option regarding residual life. Crack paths are analysed in all 5 plates to explain such a behaviour, indicating benefits of initial crack growth into length, followed by growth into depth.

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Keywords: xFEM, fatigue crack growth, orthopedic plate

1. Main text

Fatigue fracturing has shown to be the most common failure mode of in-service orthopedic plates, [1]. Fatigue, as a process of defect accumulation, i.e. crack initiation and propagation due to bending cycles, is likely to occur even under low cycling load. Also, orthopedic surgeon's experience is crucial for avoiding overloads of the implant due to

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incorrect implantation, which can easily cause crack initiation in combination with inevitable stress concentration. Figure 1 presents cracking and fatigue failure of an orthopedic plate.

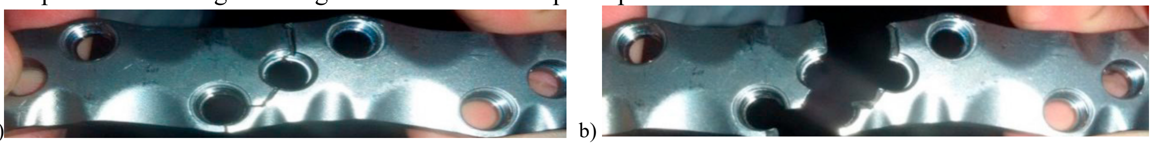
a) b)


Fig. 1. a) Cracking and b) failure of an orthopedic plate

Numerical simulations are widely used for analysing different behaviour of various implants, such as artificial hips, orthopedic plates and dental implants, including structural integrity, [2-8] and life assessment, [9-12]. This study considers different orthopedic plate designs, under uniaxial bending, with cracks initiated at the stress concentration areas. Toward this aim, numerical simulations by extended finite element method (xFEM) are made to evaluate remaining life of orthopedic plates depending on different geometries, so that the optimal one can be selected.

2. Fatigue crack growth simulation in orthopedic plates by the extended Finite Element Method

Modeling of cracks by using classical FEM approach, requires mesh to contain discontinuity of geometry. Problem is even more complicated if crack growth is considered, requiring re-meshing after every step of crack growth. The xFEM enables modeling of arbitrary crack shape without modification of mesh when crack grows, [12-13].

Later on some modifications are introduced, [14] and commercial software developed, like the one used here, ANSYS [15]. In any case xFEM has become a standard for numerical simulation of fatigue crack growth, as shown in number of successful applications, summarized in [16], and shown in details in [17-21].

Extended finite element method (XFEM) in ANSYS software was used for simulating the fatigue crack growth in orthopaedic plates. Analysis includes 5 different plate geometries, marked with: A, B, C, D and E. Cross section B-B on each plate's drawing shows the location and size (R = 0.5 mm) of initial cracks. Material parameters: Re = 1020 MPa, Rm = 1074 MPa, E = 96 GPa, ν = 0,35, C = 3,70x10^{-13}, m = 2,31. Figure 2 show geometry for all 5 plates.

Three different body weights have been considered for simulation of four-point bend testing, applying the maximal bending moments in upper tibia region, as calculated according to [22], and shown in Table 3. Total of 60 steps were set in ANSYS.

Table 1. Loading according to ref. [9].

Plate type	60 kg BW kN	90 kg BW kN	120 kg BW kN
A	2.2	3.3	4.4
B	2.2	3.3	4.4
C	2.2	3.3	4.4
D	2.6	3.9	5.2
E	2.3	3.45	4.6

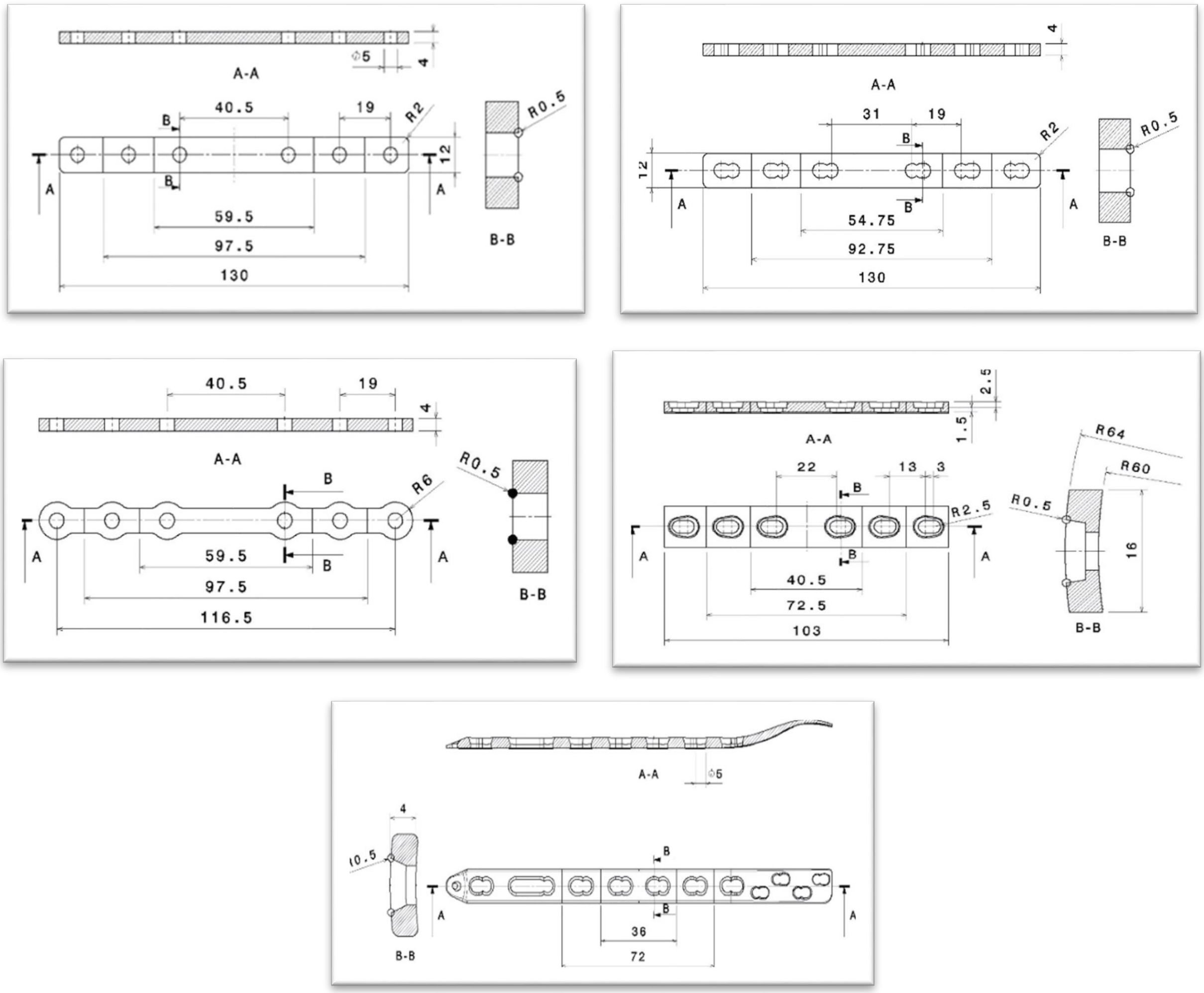


Fig. 2. Differnet shapes of orthopedic plates from A to E

3. Results

Results are shown in Fig. 3-6 for plates B-E, respectively (plate A is already presented in [9], in form of crack growth paths. One can see that the maximal obtained crack length is more than 2 mm longer than the plate thicknesses. This is explained by crack growth equally through the plate thickness and along the surface, up to the point where the crack predominantly starts propagating along the surface.

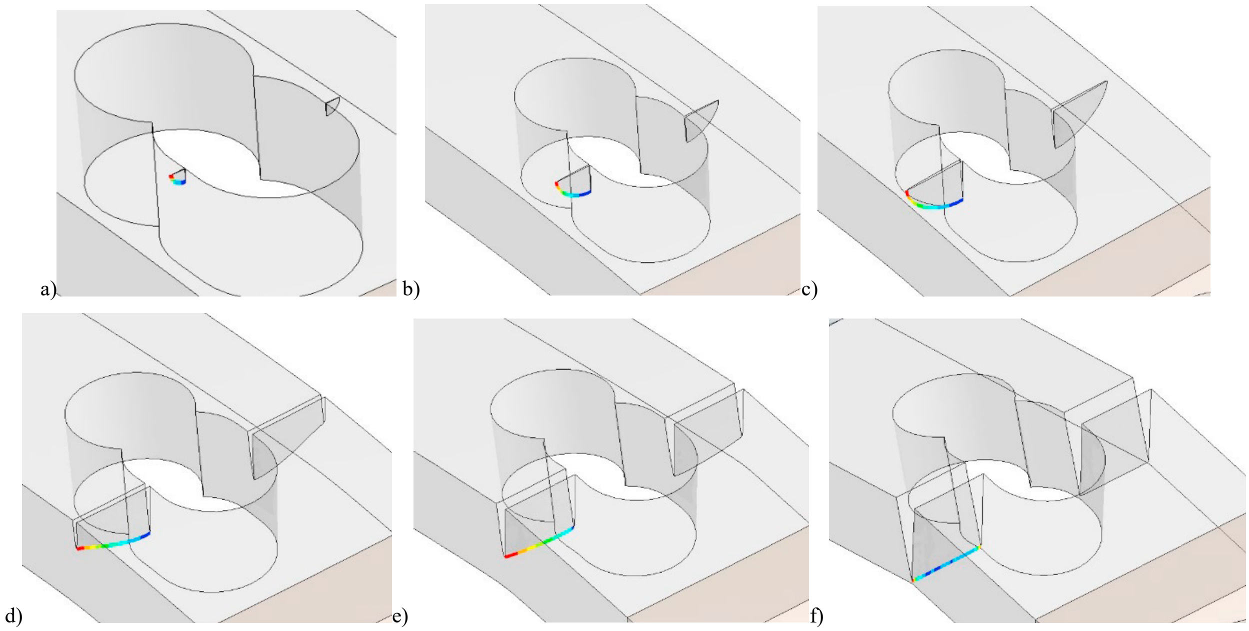


Fig. 3. Crack growth in plate B after a) 2537, b) 18183, c) 24573, d) 26017, e) 26499, f) 26595 cycles

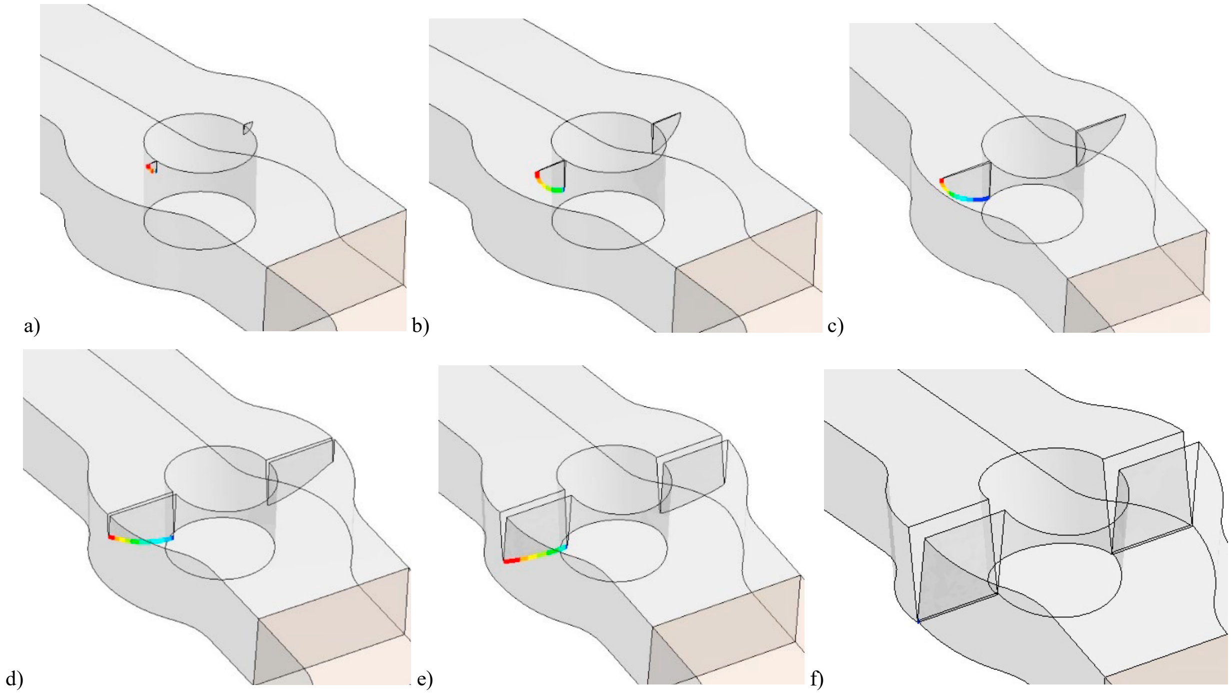


Fig. 4. Crack growth in plate C after a) 1363, b) 9967, c) 14987, d) 16499, e) 16856, f) 16919 cycles

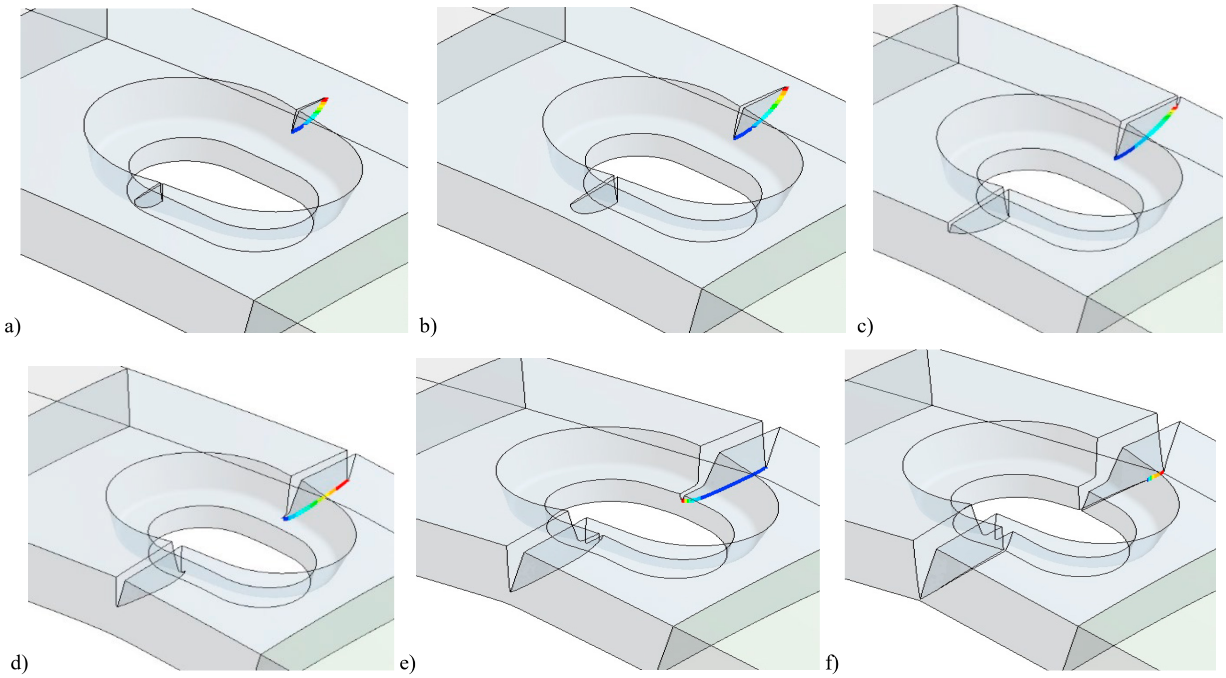


Fig. 5. Crack growth in plate D after a) 3946, b) 34365, c) 37677, d) 38682, e) 39016, f) 39029 cycles

Results for the crack length vs. number of cycles are presented in Fig. 7 for the loading 90 kg, for all 5 different plate geometries. One can see significant differences in life of different geometries, indicating plate D as far the best option.

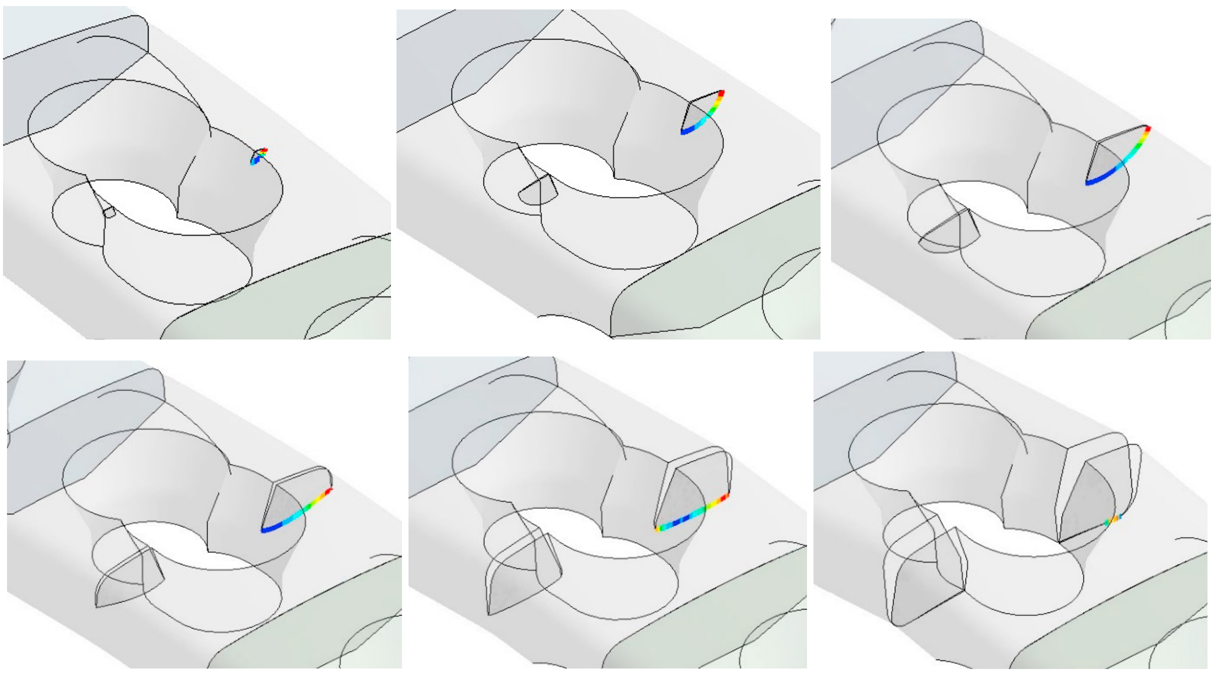


Fig. 6. Crack growth in plate E after a) 3946, b) 34365, c) 37677, d) 38682, e) 39016, f) 39029 cycles

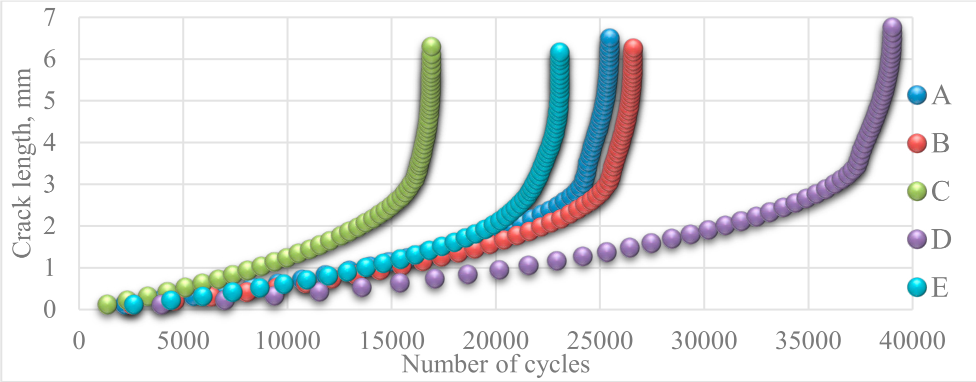


Fig. 7. (a) first picture; (b) second picture.

4. Conclusions

Based on the presented results one can conclude the following that the plate designed for providing most of contact with bone surface has the longest remaining life. This is made possible by changing the direction of crack growth from thickness to the surface and vice versa. Namely, when the surface growth is finished, crack starts growing through the thickness again. This information can be taken in consideration when designing the plates in order to prolong the remaining life after crack initiation. Finally, one can say that the crack grow path is the most important aspect in this analysis.

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