The Fatigue Prediction of Devices for Long-bone Osteosynthesis

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Abstract: This article deals with fatigue life prediction of metallic bone plates using SIMULIA fe-safe software and compare predicted results with measured data from experiments. Two materials commonly used for surgical implants were considered: stainless steel for implants 1.4441 (ASTM F138) and titanium alloy Ti6Al4V ELI (ASTM F136). Four-point bending fatigue test was carried out to obtain material parameters of both materials. The fatigue analysis based on FEA results from Abaqus was performed using the obtained material parameters. The results of the fe-safe fatigue analysis were verified by comparing them with data from measurements.

Keywords: prediction; fatigue; osteosynthesis; implants.

1 Introduction

The bone plates are in their application in human body subject to relatively high stress, that may lead to exceeding the ultimate strength of the material or more likely to the fatigue failure [1, 2]. Failure of the bone plate may cause an additional injury and further complications for the patient and leads to excessive costs related to the reoperation [3, 4]. Therefore, every new product needs to be tested to examine its fatigue endurance. However, fatigue experiments are quite expensive and time consuming and in the development process of new product there are usually several prototypes with different geometry, which needs to be tested to compare their fatigue properties. So, it would be interesting and useful to investigate, if there is a possibility to reliably predict the fatigue life of the bone plates [5, 6].

2 Methods and materials

Methodology of the four-point bending test was based on ASTM F382 standard, which describes static and cyclic testing of metallic bone plates. First, the static four-point bending test was performed to determine suitable loading levels for the fatigue four-point bending test. Afterwards, the load-controlled high-cycle fatigue test on several loading levels was done. The applied force had sinusoidal course with R ratio equals to 0.1. To obtain material properties the four-point bending fatigue test with flat specimens with rectangular cross section was performed and the S-N curve were got.

The experiments were carried out with two generations of bone plates for proximal humerus fractures and two materials (see Fig. 1). The stainless steel for implants 1.4441 (ASTM F138) and titanium alloy Ti6Al4V ELI (ASTM F136) were used. Both materials are commonly used for orthopaedic implants. The data evaluated from experiments were used to define material parameters in SIMULIA fe-safe based on elastic FEA (Finite Element Analysis) [7]. Models of bone plates were made and loaded in four-point bending mode in the same configuration as in the experiments. To perform the analysis two stress-based fatigue algorithms were used: von Mises algorithm and Normal Stress algorithm.

The fatigue analysis based on the elastic FEA results was applied in the fe-safe software. The static analysis required to gather these results was performed in Abaqus software. Models of three generations of bone plates (see Fig. 2) were created and loaded in the four-point bending mode in the same configuration as in the experiments. Each bone plate was loaded up to 1,000 N in Abaqus. The results of the Abaqus analysis (in *.odb file format) were used as input data for the fe-safe processing.

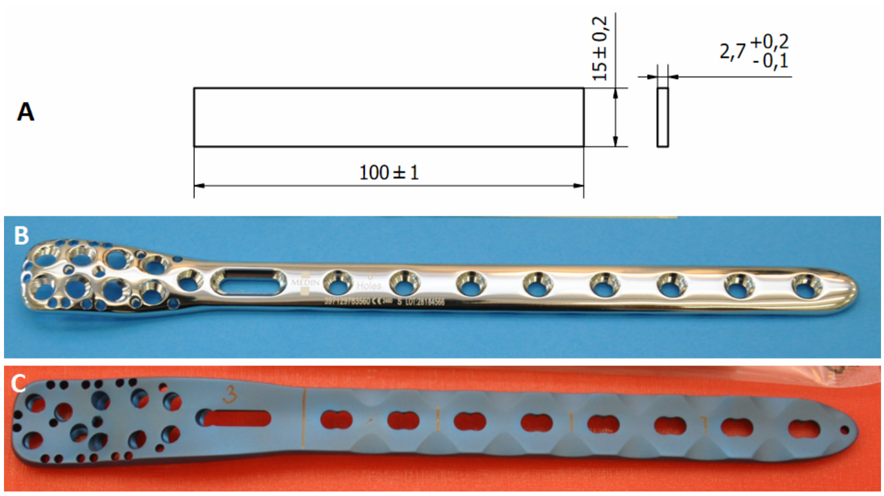


Fig. 1: (A) Dimensions of the flat sample for the four-point bending test, (B) stainless steel bone plate of the first generation, (C) titanium alloy bone plate of the second generation.

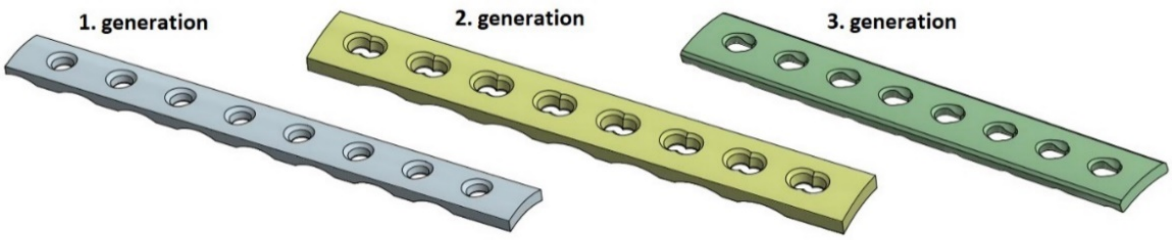


Fig. 2: Models of three generations of bone plates.

The output of the fe-safe analysis comprise the number of cycles calculated for the highest loaded node in the model, in other words the lowest lifetime calculated for the whole part. It was also possible to export the results to the *.odb file format and to display them in Abaqus as a contour plot, which showed the calculated fatigue life for the whole of the model (see Fig. 3).

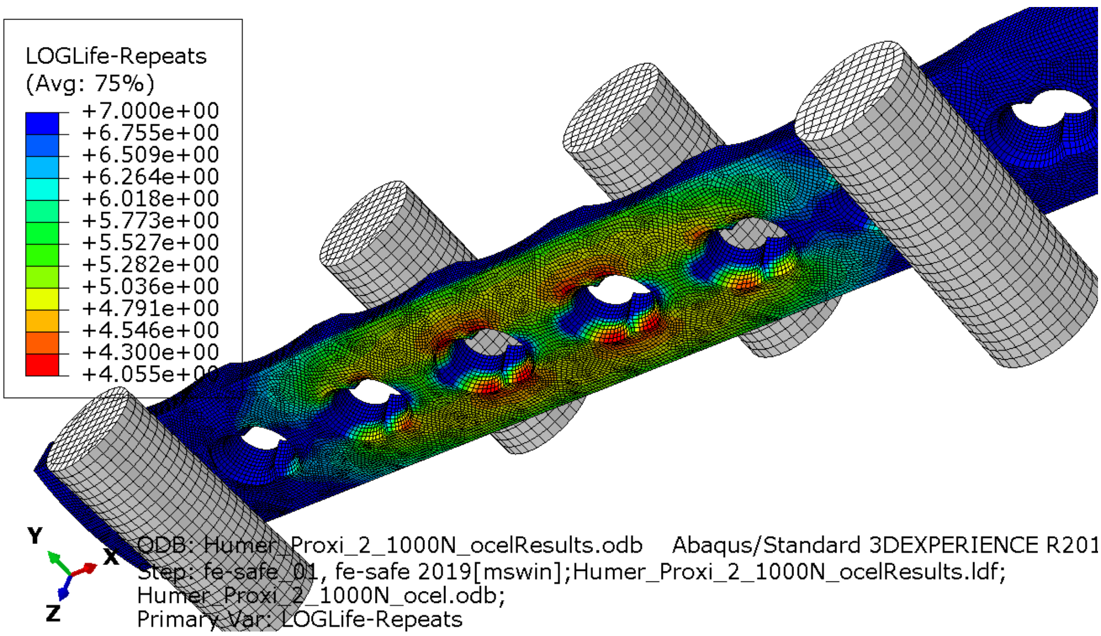
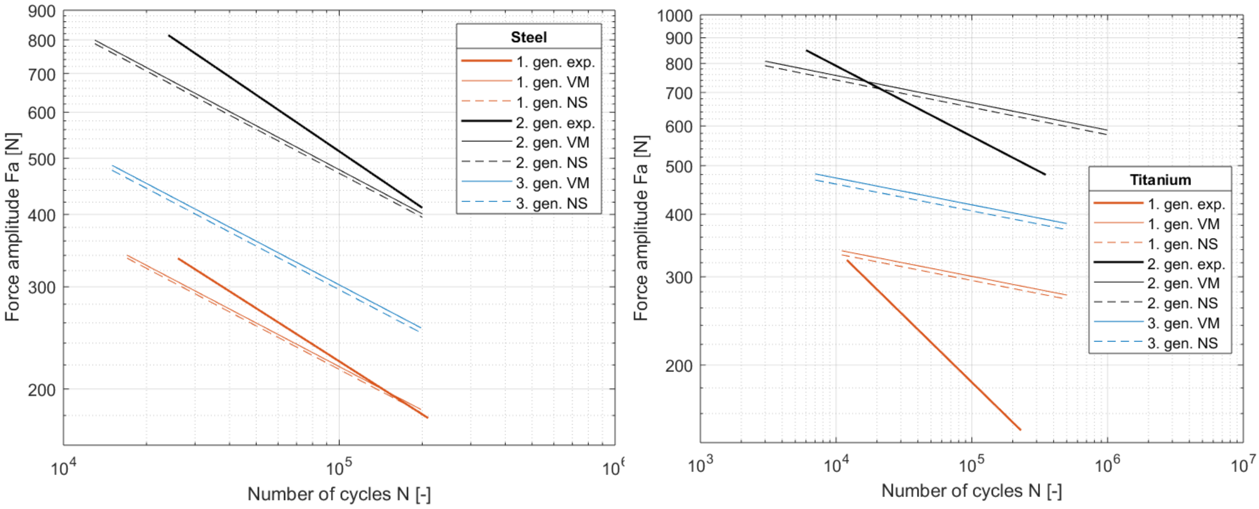


Fig. 3: Results of the fe-safe analysis for the second generation of steel bone plates displayed as a contour plot in Abaqus.

3 Results and discussion

The fe-safe analysis was run for three generations of bone plates in two material variants. The prediction results compared with experiments plotted in force amplitude are shown in the chart (see Fig. 4). The experiments are displayed as thick lines and the predictions as thinner ones, the graph contains results of both used algorithms: von Mises (VM) and Normal Stress (NS). The prediction was made for three generations, but the experiments only for the first and the second generation, because the third generation of bone plates has not been manufactured yet. Prediction for the third generation lies between the first and the second generation, this corresponds with its geometry, which is a compromise between the first and the second generation.



(a) steel (b) titanium

Fig. 4: Comparation of experiments and fe-safe results for all generations in stress amplitude.

The fe-safe prediction for steel is quite accurate although it predicts lower fatigue life, especially for higher stress amplitudes. However, the prediction for third generation in comparation with predictions and experiments for the first and the second generation shows us, where we could expect the results of experiment with the third generation. Results of the prediction for titanium do not really correspond with the experiments. Worse results might be caused by the input material parameters, which were for titanium computed with lower coefficient of determination or it may be caused by various quality of used titanium material.

4 Conclusion

SIMULIA fe-safe software was used for fatigue life prediction of bone plates in two material options. The prediction was based on FEA results from Abaqus and material parameters obtained from experiments. The fe-safe analysis results were compared with the measured data from experiments. Satisfying correspondence between the prediction and the experiments for the titanium alloy was not achieved. However, the prediction for the stainless steel shows better results and could be used to estimate fatigue life of bone plates with different geometry.

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