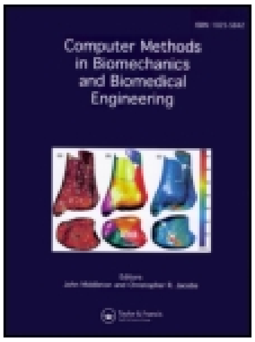

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Numerical durability evaluation of Nitinol stent

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Keywords: Nitinol; shape memory alloys; fatigue; finite element method

1. Introduction

Shape memory alloys, such as binary NiTi alloy, have gained the attention of researchers, thanks to their remarkable properties. In comparison with other usually used materials, they exhibit large reversible strains (pseudoelasticity) and especially a heat-induced regaining of their original shape even in the case of significantly large deformations (shape memory effect) (Yahia 2000; Lagoudas 2008).

Even though many articles have been written on account of these materials (Duerig et al. 1999; Kleinstreuer et al. 2008; Nayan et al. 2009), only a few deal with their fatigue properties. The need to know and understand the behaviour of the material under cyclic loading came from a project which deals with coronary Nitinol stent grafts. Stents (Figure 1), which form a skeleton of an implant, are made up of NiTi wires. After an implantation of a stent graft into a blood vessel, it is subjected to cyclic change of its diameter due to the alternation between the systolic and diastolic blood pressure.

The aim of this study was to carry out fatigue analysis of a Nitinol stent, subjected to a cyclic crush test, and to reveal critical areas of its construction. In previous work, the dependency of stress amplitude versus number of cycles until the failure of a specimen was evaluated experimentally. This dependency is called Wöhler's or the S–N curve, and is one of the basic indicators that define the fatigue properties of a material.

Thanks to our knowledge of the S–N curve of NiTi alloy, we were able to predict the life of a Nitinol stent with the support of data gained from a crush test of a stent performed using the finite element method (FEM) in MSC Marc software.

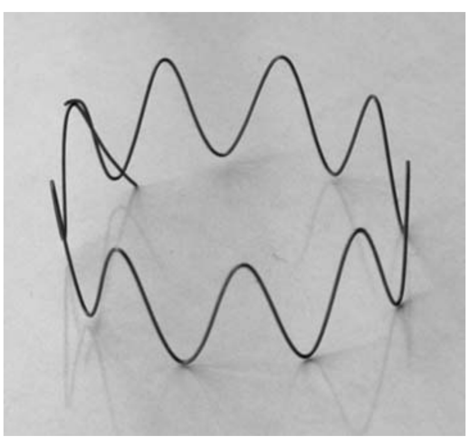

Figure 1. NiTi stent, ELLA-CS.

2. Methods

As was mentioned earlier, FEM analysis of a crush test of a stent was carried out. This test is recommended by the Center for Devices and Radiological Health (CDRH) of the USA as one of the indicators that reveal the stability of a stent. The test is quite simple: the stent is positioned between two parallel planes and then compressed by a constant displacement. In a certain point, a loss of stability, indicated by a rapid decrease in force, appears. This test is also easy to simulate numerically. The CAD model of the stent was imported from MSC Marc. Two parallel planes were defined in the program to simulate the crush test. One of them was completely fixed while the other was defined to move with a constant velocity until a certain point. The rigid/deformable type of contact was defined between planes and the stent. In Figure 2, the result of the stress distribution over the whole part is displayed. In this case, the maximal displacement of the upper plane was 15 mm (diameter of the tested stent was 30 mm).

Ordinarily, analysis converged very quickly because of the low number of elements. CPU time varied from 5 to 7 min.

Numerical life prediction of the stent was made in MSC Fatigue. This software computes several indicators of the life of the given part using knowledge of the S–N curve of the material and the way that the part is loaded. The S–N curve, evaluated in previous work is, displayed

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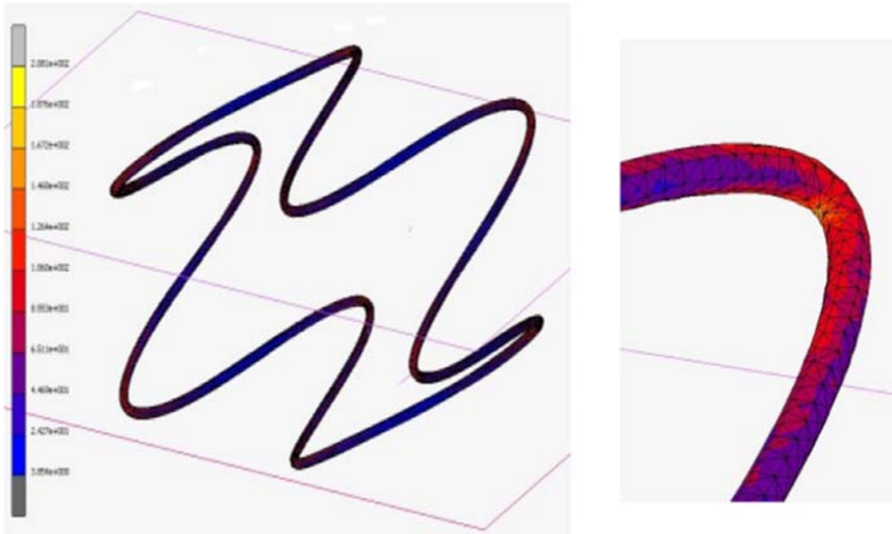

Figure 2. FEM data of a crush test from MSC Marc.

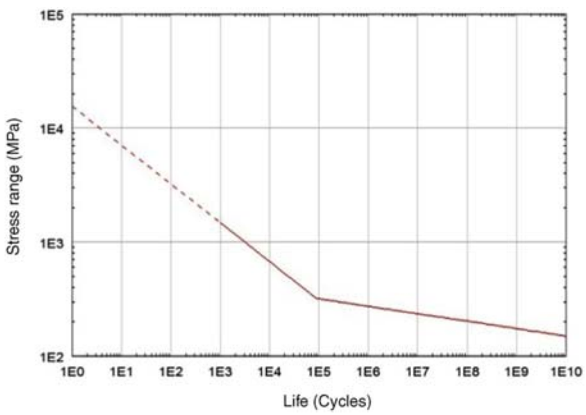

Figure 3. S–N curve of NiTi alloy.

in Figure 3. The dependency is driven by the power law. Nevertheless, curves appear linear because both axes are set to a logarithmic scale.

The model of the stent was loaded by a sinusoidal signal that causes alternation of the stress given by MSC Marc from 0 MPa up to its maximal value.

3. Results and discussion

The result gained from a numerical analysis in MSC Fatigue is displayed in Figure 4. The selected display shows how many cycles certain parts of the tested stents will endure until a rupture. The first noticeable thing is the location of parts which might endure the fewest cycles.

Figure 4. MSC Fatigue analysis result.

These locations are displayed in red, and according to the results, will last only around 8000 cycles until failure of the material.

The number of cycles until failure cannot, of course, be taken as an exact number. There are many factors influencing the evaluation not only on the side of durability analysis in MSC Fatigue but also on the side of finite element analysis. This piece of knowledge must be taken into account when performing any numerical evaluation.

Nonetheless, results show us on which parts of the tested piece, from a fatigue point of view, our attention should be focused.

4. Conclusions

Durability analysis of a Nitinol stent was carried out in a numerical way. The analysis revealed that a problematic part of a stent would be in the bends of the wire. Even the results of previous FEM revealed a stress concentration in these parts. Most probably, the cyclic change in a stress will result in a defect in this part earlier than in the others.

Comparison of results with those of other authors (Migliavacca et al. 2002; Kleinstreuer et al. 2008; Nayan et al. 2009) showed no major errors when comparing the shape and significant points of the S–N curve.

The data will be used as a base for an optimisation process in order to increase the durability of the stent and to prevent cracks in the material while the stent is implanted.

Acknowledgements

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