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USE OF NONLINEAR MATERIAL BEHAVIOR WITH FEM-AIDED MATERIAL SELECTION

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Abstract: This paper follows up the initiative to derive material indices and support material selection using finite element method. Material indices are a very useful tool helping with comparing different materials based on their properties performance in various applications. In this paper nonlinear material behaviour is introduced in this process demonstrated on a rubber seal application with self-contact.

Keywords: *materials selection, FEM, nonlinear, material indices, Abaqus*

1. INTRODUCTION

When creating a product material selection plays an essential role that significantly influences its properties. The methodology of materials selection described in [1] involves following steps. Firstly there are requirements on the product that can be broken down into four main groups: functions, constraints, objectives and finally free variables. The purpose of the product is defined by its function, e.g. to transmit force. Usually there are some boundaries that cannot be exceeded, such as total dimension or weight. These are expressed by constraints. When designing a product we also aim for some target or an objective. The product aims to be the best in terms of e.g. power output. Finally we are left with free variables that can be adapted to accomplish our objective and make the most of it.

In *Figure 1* this is summarized by the first row. The important step is to translate the entities in the first row into a measure that can be used for quantifying, comparing and ranking. In this case the measure is called a material index. Based on the value of the index we can sort the materials and determine how suitable they are for our product based on the given properties.

Below you can find a simple performance equation for mass of an oar loaded in bending [1]:

$$m = \left(\frac{4\pi S^* L^3}{3} \right)^{\frac{1}{2}} \cdot (L) \cdot \left(\frac{\rho}{E^{\frac{1}{2}}} \right) \tag{1}$$

The first bracket represents stiffness properties, the second term *L* stands for dimensional requirements and the last fraction represents the material index. The material index from the equation above is a typical example of indices presented in [1]. These indices were derived for very simple linear problems such a simple tension and bending. In our previous papers on this topic we involved finite element method in the process of material selection. This approach proved to be useful when dealing with more complicated problems involving different load cases and geometries [4, 6, 7]. This paper makes a step further and introduces how to take into account material nonlinearity.

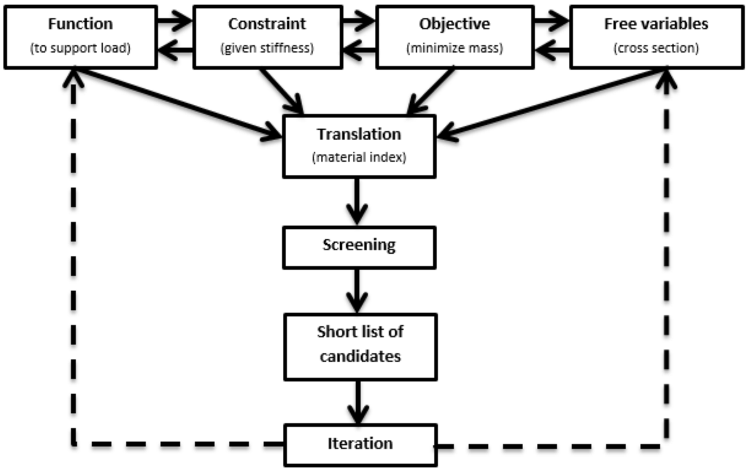

Figure 1. Materials selection process [4]

2. NEO-HOOKEAN NONLINEAR MODEL

The Neo-Hookean model is a rather simple nonlinear model suitable for hyperelastic materials that are similar in behaviour to rubber. This material model will be used further in the paper. Its strain energy potential is given by the following equation [3]:

$$U = C_{10}(\bar{I}_1 - 3) + \frac{1}{D_1}\left(J^{el} - 1\right)^2, \tag{2}$$

Where U stands for the strain energy per unit of volume; C10 and D1 are material parameters that are temperature-dependant. I1 is the first deviatoric strain invariant which is defined in the following way [3]:

$$\bar{I}_1 = \bar{\lambda}_1^{\ 2} + \bar{\lambda}_2^{\ 2} + \bar{\lambda}_3^{\ 2}, \tag{3}$$

Deviatoric stretches are defined as [3]:

$$\bar{\lambda}_i = J^{-\frac{1}{3}} \lambda_i, \tag{4}$$

Where J is the total volume ratio; J^{el} is the elastic volume ratio and λ_i stands for the i-th principal stretch. Bulk modulus and initial shear modulus are given by [3]:

$$K_0 = \frac{2}{D_1}, \mu_0 = 2C_{10} \tag{5}$$

Figure 2 below shows a typical response of a Neo-Hookean material model as a stress-strain curve.

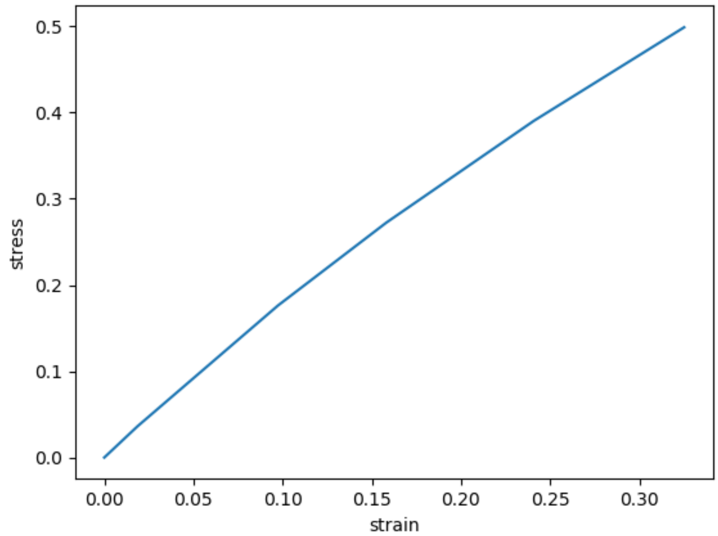

Figure 2. Stress-strain curve – Neo-Hookean

3. Self-Contacting Rubber Seal Example

The methodology will be demonstrated on a rubber seal example. The complexity of the chosen problem is due to occurrence of large deformations and self-contact of the rubber seal. Therefore, an explicit solver was chosen.

The rubber seal in a steel housing and an upper flange displayed as a line body can be seen in the *Figure 3* below.

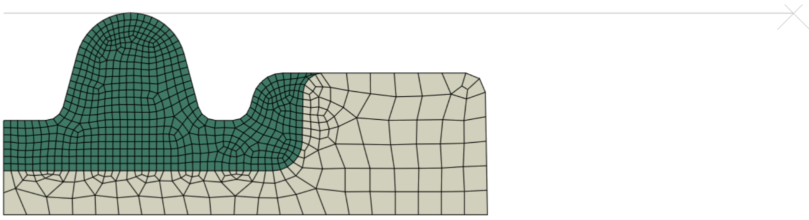

Figure 3. Rubber seal – undeformed state

An example of the rubber seal in the deformed state is in the *Figure 4.*

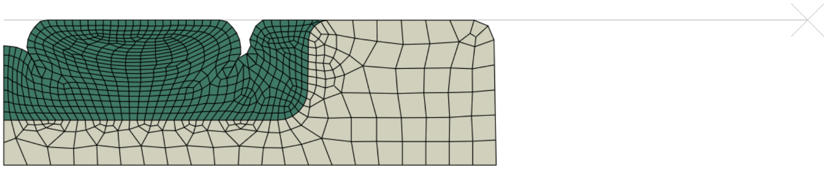

Figure 4. Rubber seal – deformed state

The analysis is setup in such way that the rigid upper flange has prescribed displacement in the vertical direction. Reaction force on the flange is measured. This represents the conditions during assembly. A range of parameters was used for both material model parameters C10 and D1. The whole design-of-experiment study consisted of 25 simulation runs. The finite element model is taken over from Abaqus documentation as is created using four-node plane strain elements CPE4R [3].

The results of the analysis as well as the fitted surface are displayed in *Figure 5* below. The horizontal axes represent D1 and C10 and the vertical axis stands for the reaction force.

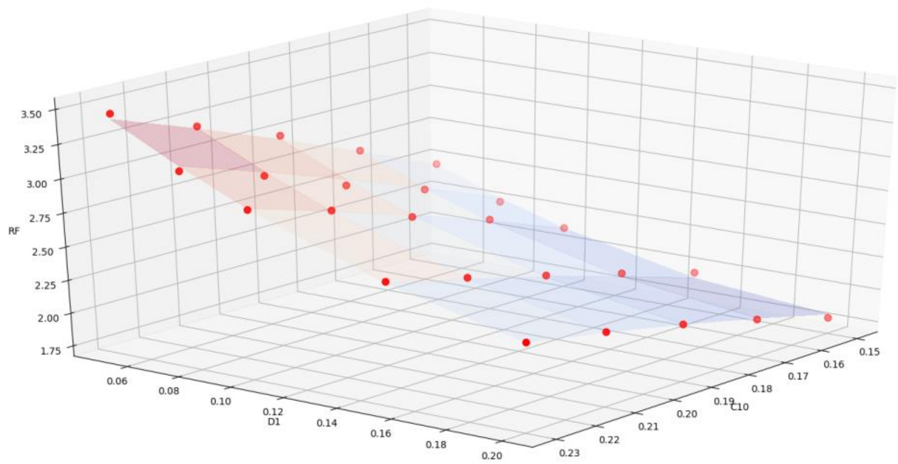

Figure 5. Results of DOE

The surface fitted to the simulation results is given by the following equation:

$$RF = k\frac{{C_{10}}^{0.669}}{{D_1}^{0.251}} \tag{3}$$

This equation also represents the material index- the second row in *Figure 1*. If we want to make a step further to the Screening phase we need to derive the C10 and D1 constants for our candidate materials and use them in *Equation 3*. Then we can search for a maximum or a minimum value depending on if we need high or low assembly force.

4. CONCLUSION

The work presented in this paper continues the extension of material indices theory first introduced in [1] currently involving also the use of nonlinear materials. Parameters of a material model are subjected to a design-of-experiment simulation and a mathematical surface is fitted to the results. The equation of the surface contains the parameters of the model and determines the material index. We can search for the suitable materials based on their stress strain curve assuming that the material model is sophisticated enough to describe the true behaviour of the material correctly.

ACKNOWLEDGEMENT

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