Experimental Investigation Concerning the Material Behavior of High-Pressure Hydraulic Hoses

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Introduction

The characteristics of multi-layered high-pressure hydraulic hoses are mainly determined by the mechanical properties of the single materials used, like rubber and wire or textile reinforcements, and in addition by the interaction behavior between these parts. The objective of the presented experimental study is to provide reliable material data of the discrete materials under realistic loading conditions as well as of the composite structure itself.

In numerical stress analyses of elastomer hoses realistic hyperelastic material models are necessary. The identification of the required material parameters is mostly done by means of uniaxial test data only. However, for an adequate description of the real material behavior of rubber and rubber composites tests with more complex loading situations have to be carried out.

Biaxial Membrane Stress Tests

In practice, the calibration of even highly sophisticated hyperelastic material models is done frequently by uniaxial test data only. This yields to a bad representation of the real mechanical behavior of incompressible materials under large deformations. Therefore, besides of the measurement of compressibility of the rubber used, a bubble inflation method resulting in an equi-biaxial tensile testing is suggested.

Depending on the internal pressure p_i the change of the radius, Δr, of a marked circle at the surface of the specimen (diameter: $2r_0$) as well as the increase of the radius of curvature of the sphere is measured during the test. The components of stress and stretch, σ_i and λ_i, at the pole of the calotte, necessary for the calibration procedure, can be calculated by means of the given set of equations.

Surface Profile Measurements

High-pressure hoses with a reinforcement of plaited wires subjected to an increasing internal pressure fail usually by bursting. In this case the rubber material exhibits significant spatial stress states. For calibration of a material model and for validation of a numerical simulation model a suitable test set-up was developed.

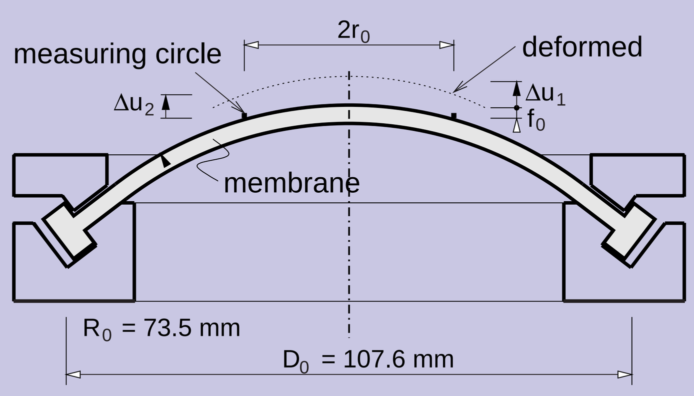
A hose with a partially removed cover layer is subjected to an increasing internal pressure. Because of this loading the inner layer of rubber will be pressed through gaps between the reinforcing wires causing bulges at the surface. The resulting surface profile is recorded for different pressure levels up to a bursting pressure of 200 to 1500 bar. The deformation analysis is performed through distance measuring by means of laser triangularization with a so-called Laser-Twin-Sensor. It has an accuracy of approximately 1 µm.

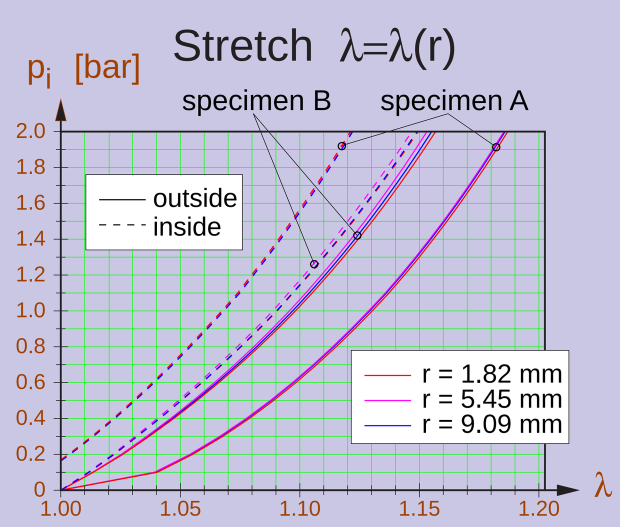
Crimpling of a Hose Fitting

The results of a numerical simulation of the crimpling of a hose fitting are in good agreement with experimental results. This confirms the functionality of the calculation model and the suitability of the used material parameter.

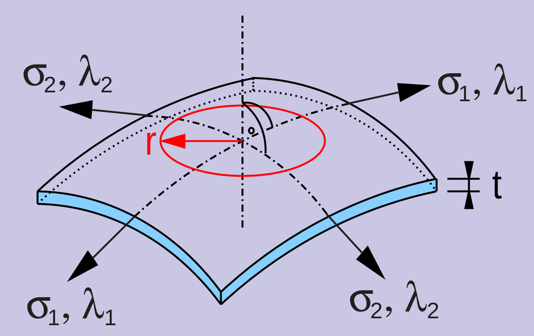
Biaxial Membrane Stress Test

Biaxial Membrane Specimen





Determination of Stretch and Stress Components



pole of a sphere calotte

$$\alpha_0 = \arcsin\left(\frac{r_0}{R_0}\right)$$

$$\alpha = \arcsin\left(\frac{r_0+\Delta r}{R}\right)$$

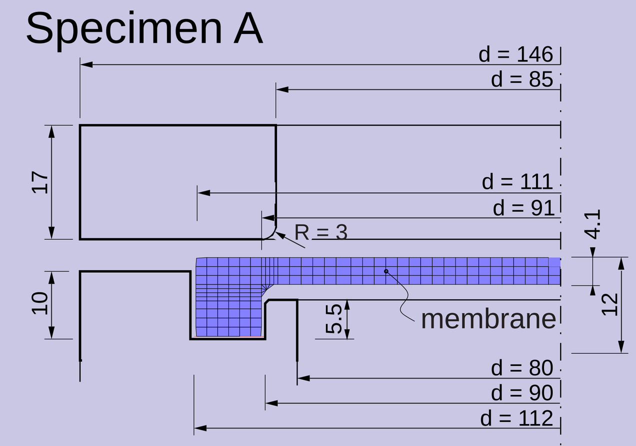
$$\lambda_1 = \lambda_2 = \frac{R\alpha^{rad}}{R_0\alpha_0^{rad}}$$

$$\lambda_3 = \frac{1}{\lambda_1\lambda_2} = \left(\frac{R_0\alpha_0^{rad}}{R\alpha^{rad}}\right)^2$$

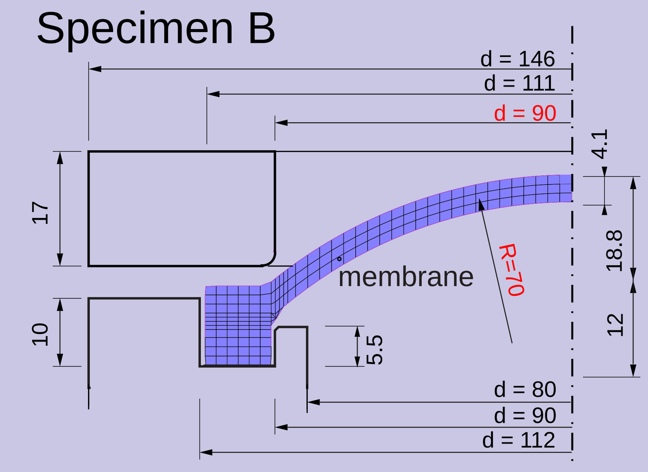
$$\sigma_1 = \sigma_2 = \frac{R}{2t\lambda_3}\,p_i$$

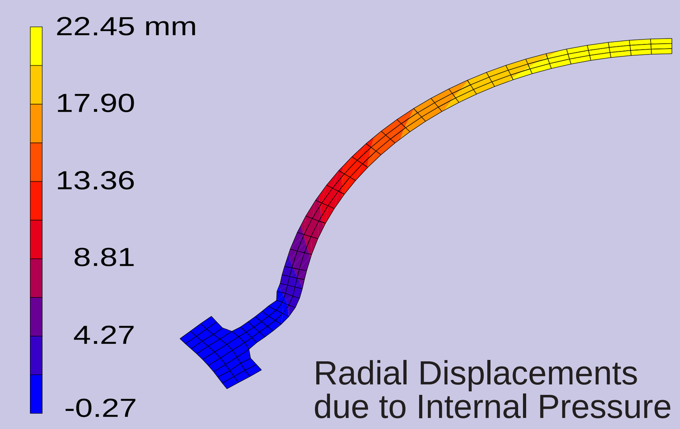
$$\sigma_3 = 0$$

Specimen A



Specimen B

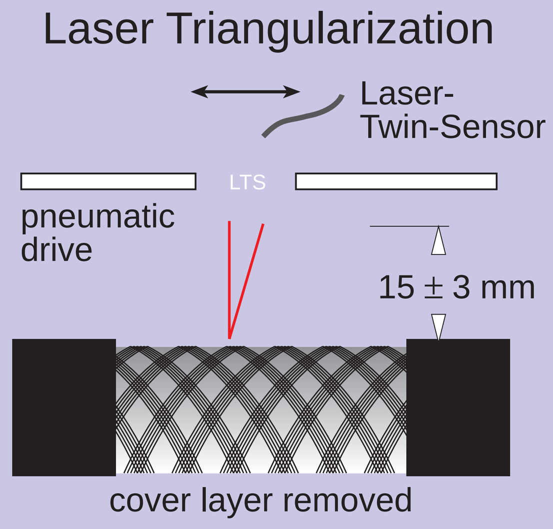


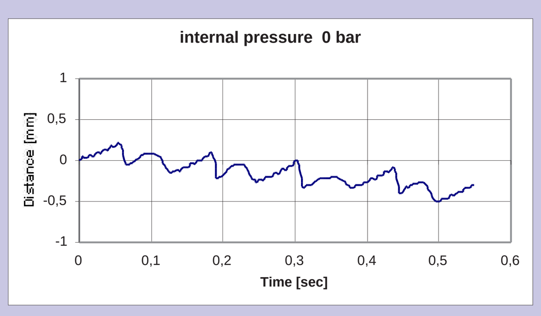


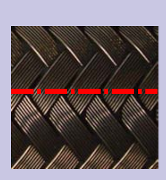
Surface Profile Measurement

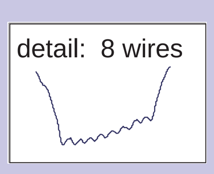
Partially Peeled Hose

Laser Triangularization

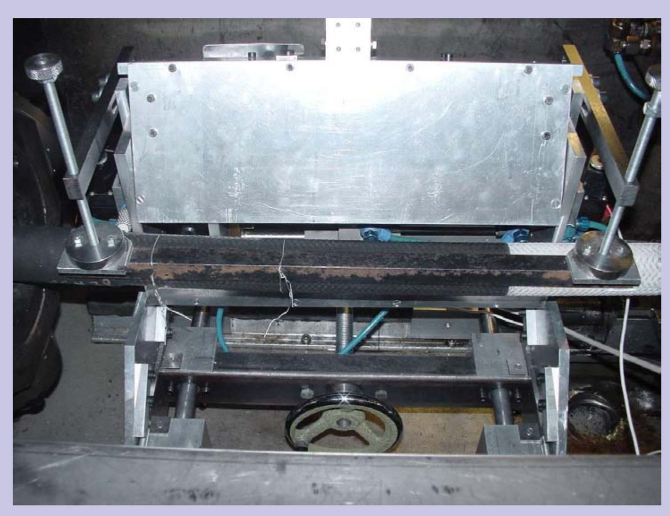


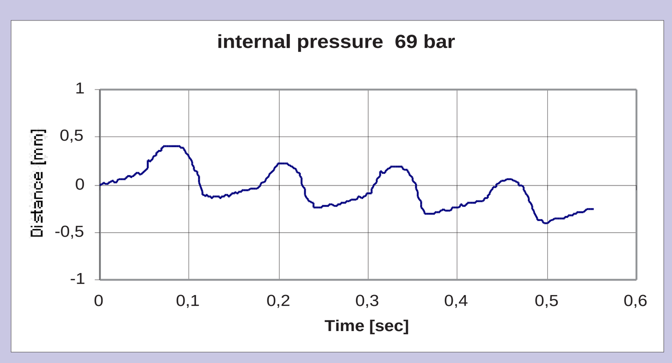


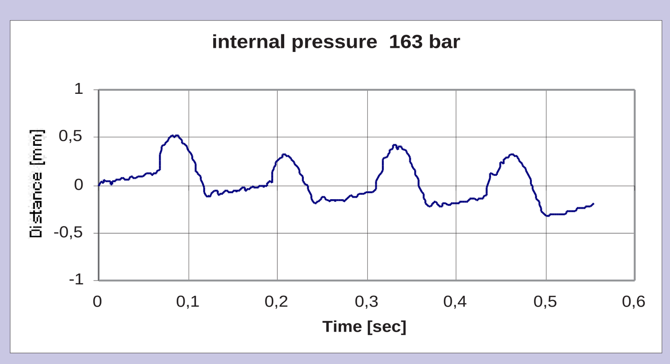




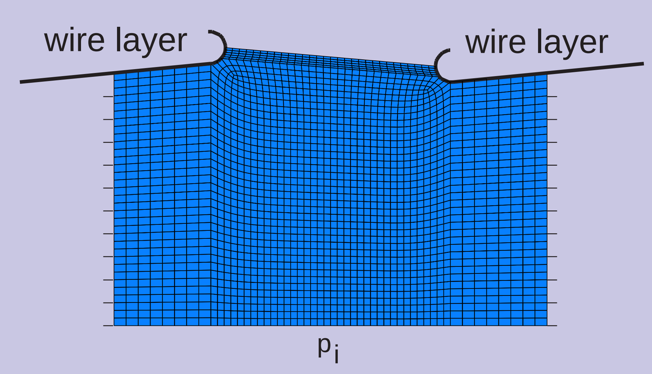
Measuring System & Testing Device

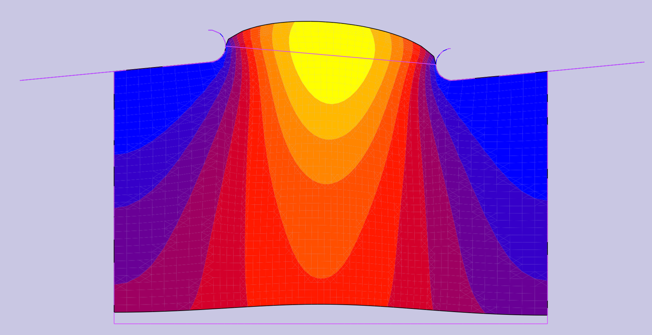




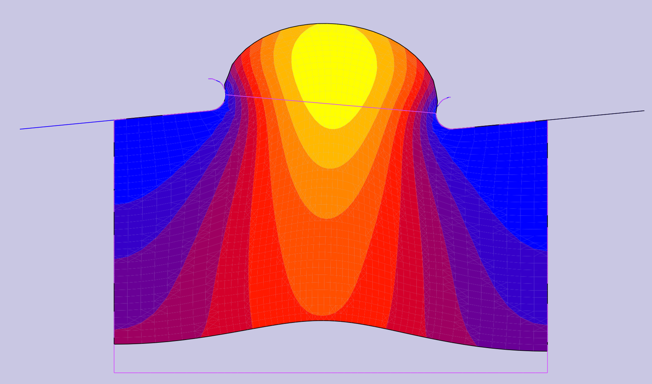


Finite Element Simulation





internal pressure: 69 bar



internal pressure: 163 bar

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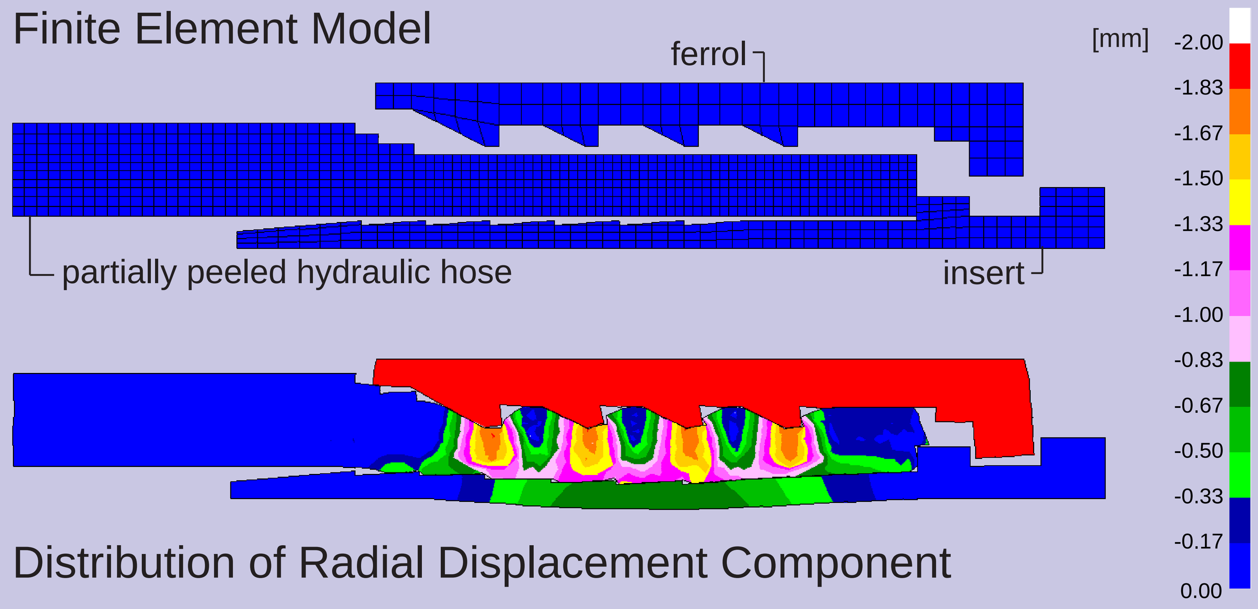
Crimpling of a Hose Fitting

Finite Element Model



Distribution of Radial Displacement Component