FACULTY OF MECHANICAL ENGINEERING — institute of solid mechanics, mechatronics and biomechanics

Experimental mechanics (REM)

Name:	Václav Valíček	
Elaboration date:	17.1.2019	
Assigment name:	**Strongly curved rod**	
Supervisor	Ing. Petr Krejčí, Ph.D.	Evaluation:

Assignment

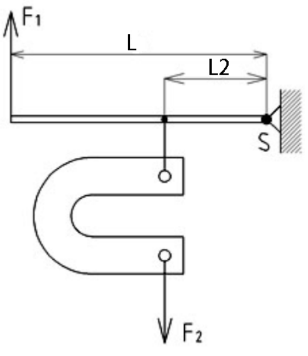
Identify stress distribution in cross section of strongly curved rod loaded with bend. Define stress distribution:

1. Experimentally
2. Numerically

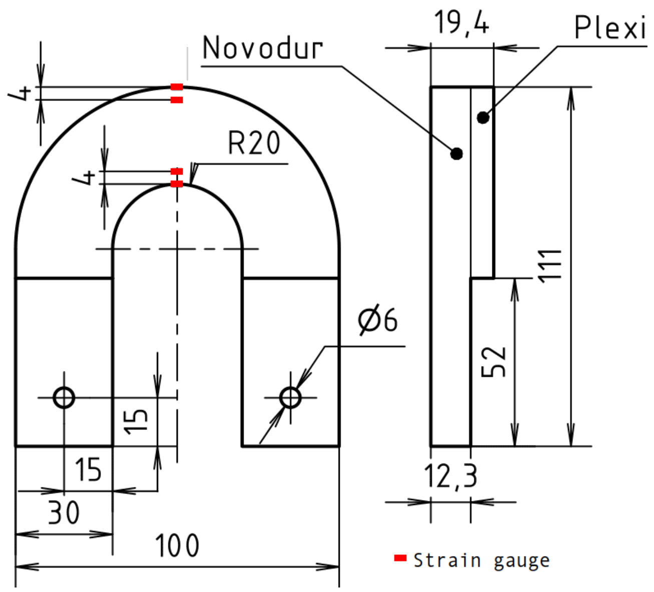
Experiment

Overview

The experiment was performed on apparatus shown below (see fig. 1a). Dimensions of "rod" are evident fom figure 1b. There were four strain gauges placed on examined axis, all wired in 1/4 Wheatstone bridge. Used strain gauge amplifier was HBM QuantumX MX1615B. Sensor used for measuring reference force was HBM U9A.



(a) Apparatus dimensions



(b) Examined part

Figure 1: Experiment scheme

Parameters

All needed dimensions of rod are evident from figure 1b, missing material constants and lever dimensions follow.

Dimensions of lever:

$$L_2 = 262\ [mm]$$
$$L = 772\ [mm]$$

Rod's material properties:[1]

$$E = 2.86\ [GPa]$$
$$\mu = 0.4\ [-]$$

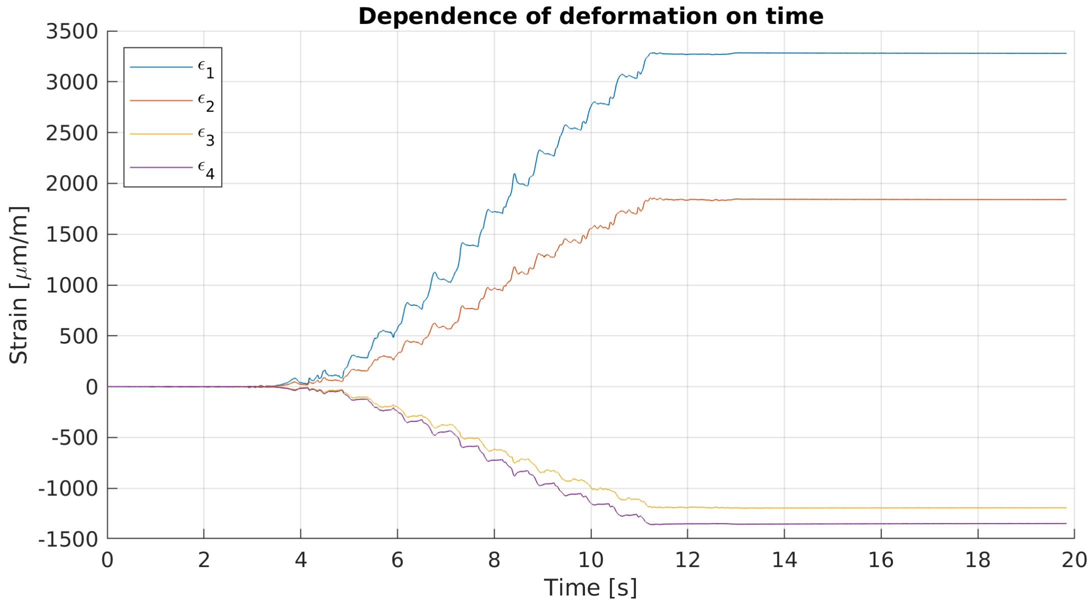
Used measuring equipment:

- 4× strain gauge, 120 Ω, Gage Factor 2, 1/4 bridge
- HBM QuantumX MX1615B - Strain gauge amplifier
- HBM U9A – Reference force sensor

Measurement

Data was measured by four strain gauges (see fig. 1b, starting from inner diameter) and single U9A force sensor.

Force acting on rod had to be calculated from lever (see fig 1a). Values used onwards are taken from steady state ($t > 15\ s$)



(a) Deformation over time

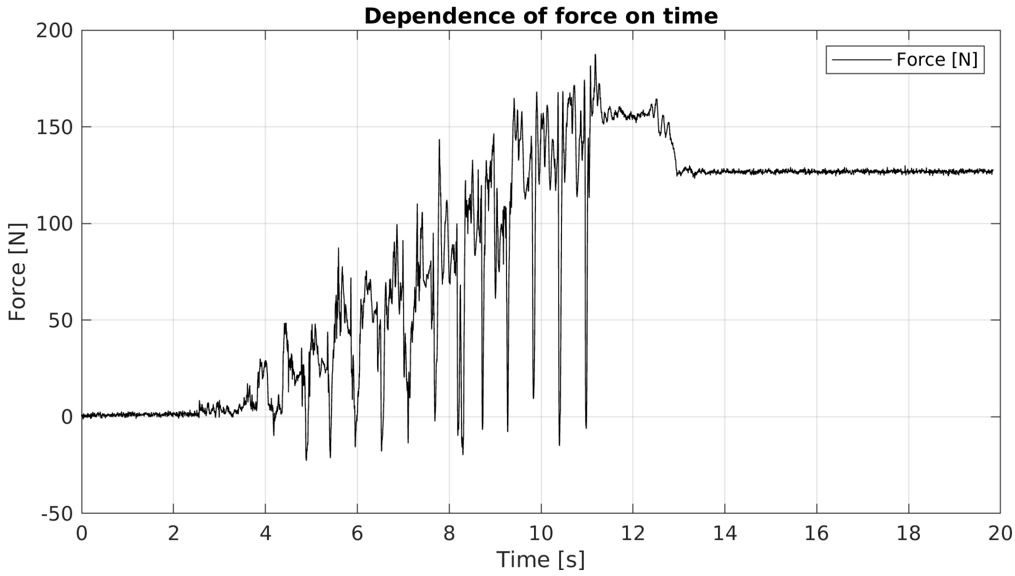
Strain data

$\epsilon_1 = 3280.4$ $[\mu m/m]$
$\epsilon_2 = 1841.4$ $[\mu m/m]$
$\epsilon_3 = -1192.5$ $[\mu m/m]$
$\epsilon_4 = -1348.3$ $[\mu m/m]$

Force:

$F_1 = 126.8\ [N]$
$F_2 = F_1 * L/L_2$
$F_2 = 373.7\ [N]$

[1]Material constants were choosen according to ANSYS material DB. Both parameters are equal for plexi and novodur.



(b) Force over time

Figure 2: Measured data

Calculation

Normal stress was calculated in cross section of the rod. The purpose was to create curve with dependence on position on cross section axis of rod with respective values of normal stress.

Experimental solution

For approximate definition of tension along the axis were used all four strain gauges plus neutral axis ($\sigma_{norm} = 0$), so there were 5 points to characterize desired curve of normal stress distribution.
Nornal stress:

$$\sigma = \epsilon * E$$

Normal stress was calculated from deformations using equation mentioned above.

$$\sigma_1 = \epsilon_1 * E = 3280.4 * 10^{-6} * 2.86 * 10^9 = \underline{9.3MPa}$$
$$\sigma_2 = \epsilon_2 * E = 1841.4 * 10^{-6} * 2.86 * 10^9 = \underline{5.2MPa}$$
$$\sigma_3 = \epsilon_3 * E = -1192.5 * 10^{-6} * 2.86 * 10^9 = \underline{-3.4MPa}$$
$$\sigma_4 = \epsilon_4 * E = -1348.3 * 10^{-6} * 2.86 * 10^9 = \underline{-3.8MPa}$$

Neutral axis: Every rod has netural axis, including strongly curved rods. Neutral axis is defined like a place where normal stress is equal to zero. To determine this location, Matlab with curve fitting support was used.

Assumptions of succesfull use of curve fitting is knowing about shape and important points of investigated function. Because we knew 4 points on cross section axis with respective values, assumptions were fullfiled.

After plotting σ_1 at 0 mm, σ_2 at 4 mm, σ_3 at 26 mm and σ_4 at 30 mm, `Tools` → `Basic Fitting` → plot fit `quadratic` was used. At place of crossing $y = 0$, we could find position of neutral axis (see fig. 3).

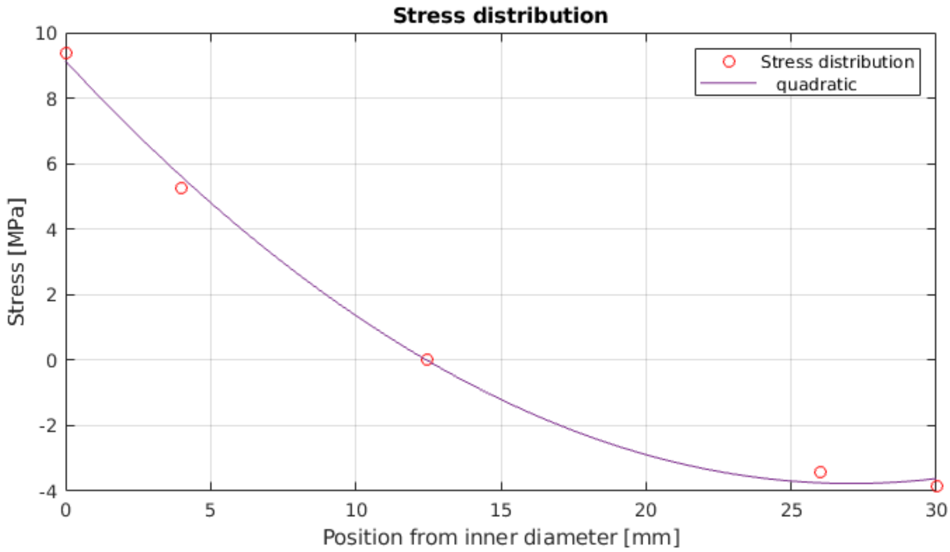


Figure 3: Curve fitting preview

<u>Matlab curve fitting results:</u>

$$y = p_1 * x^2 + p_2 * x + p_3 \qquad x_1 = 12.44\ mm$$

$$p_1 = 0.017601 \qquad 0 = p_1 * x^2 + p_2 * x + p_3 \qquad x_2 = 41.71\ mm$$

$$p_2 = -0.95311$$

$$p_3 = 9.1346$$

Let's assume that only x_1 fits physical dimensions of our rod, so we can say that neutral axis lay in distance $x_1 = 12.44\ mm$ from inner diameter of rod.

FEM Solution

For defining normal stress numerically, ANSYS software stood in. Easiest way how to obtain tension values along cross sections axis was path function.

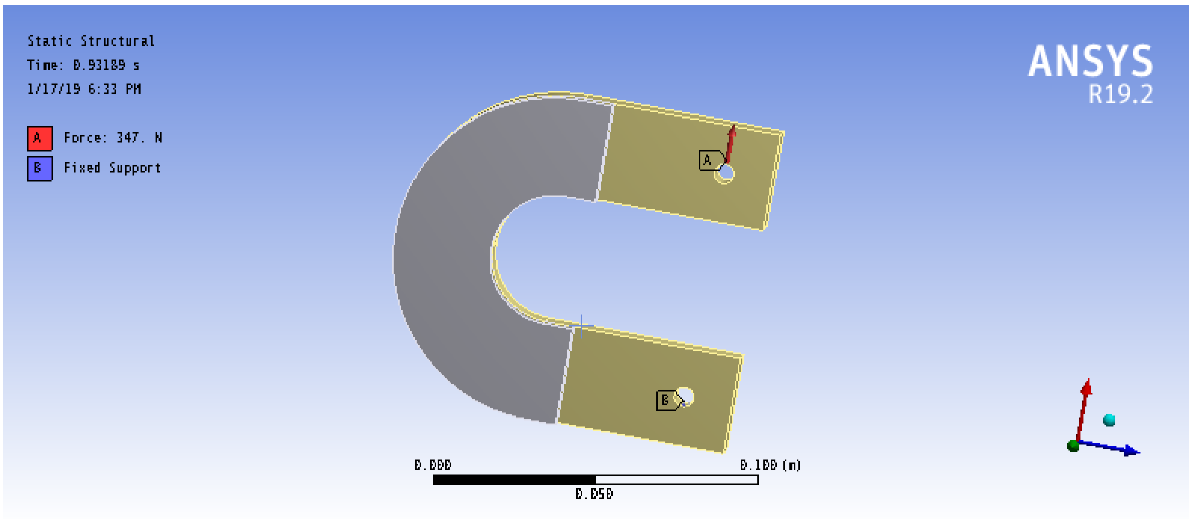


Figure 4: Model of rod with loads

Model of rod was created in Ansys, to match real situation (screw mounting) small surfaces were created inside holes to attach loads (see fig. 4). One surface (mark A) was loaded with calculated force, second (mark B) was fixed to support. Material constants were choosen from Ansys Material Database.

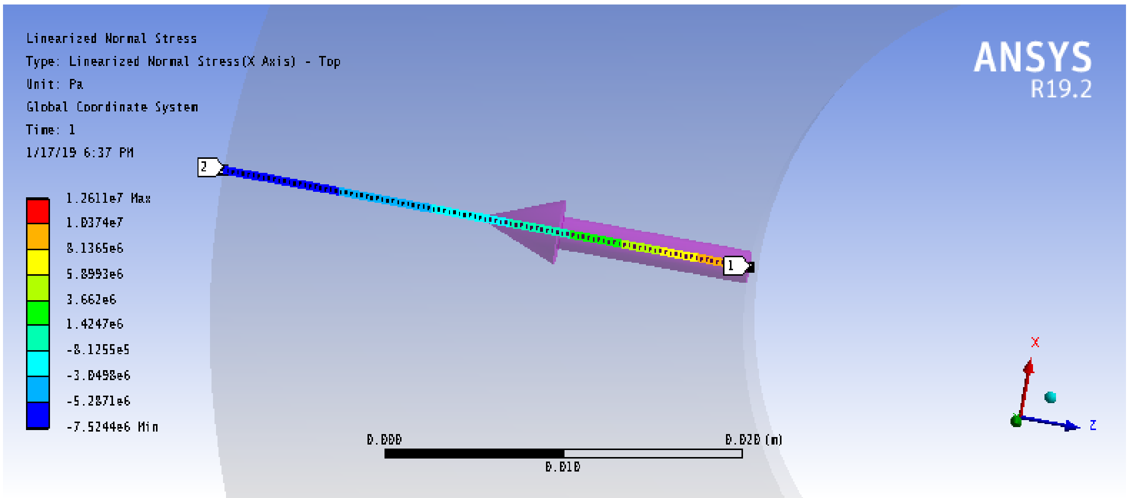


Figure 5: Normal stress represented on cross section axis

In figure 5 you can see numerical solution of normal stress distribution in rod's cross section axis, where strain gauges were placed. Data was saved into text file and plotted in figure 6.

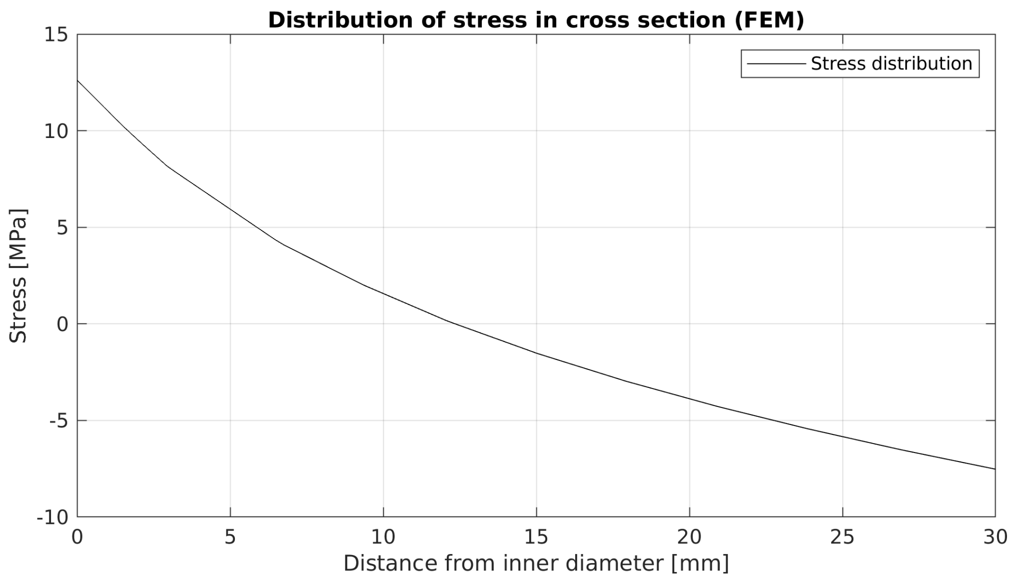


Figure 6: Graph of normal stress in dependence on distance from inned diameter of rod

Normal stress:

$\sigma_1 = 12.6\ MPa$

$\sigma_2 = 7.1\ MPa$

$\sigma_3 = -6.2\ MPa$

$\sigma_4 = -7.5\ MPa$

Neutral axis:

$n = 12.35\ mm$

Conclusion

From figure 7 is noticeable, that experimental and numerical values differ a bit. Both curves does have similar shape and both meet at neutral axis position, which is almost same for both variants.

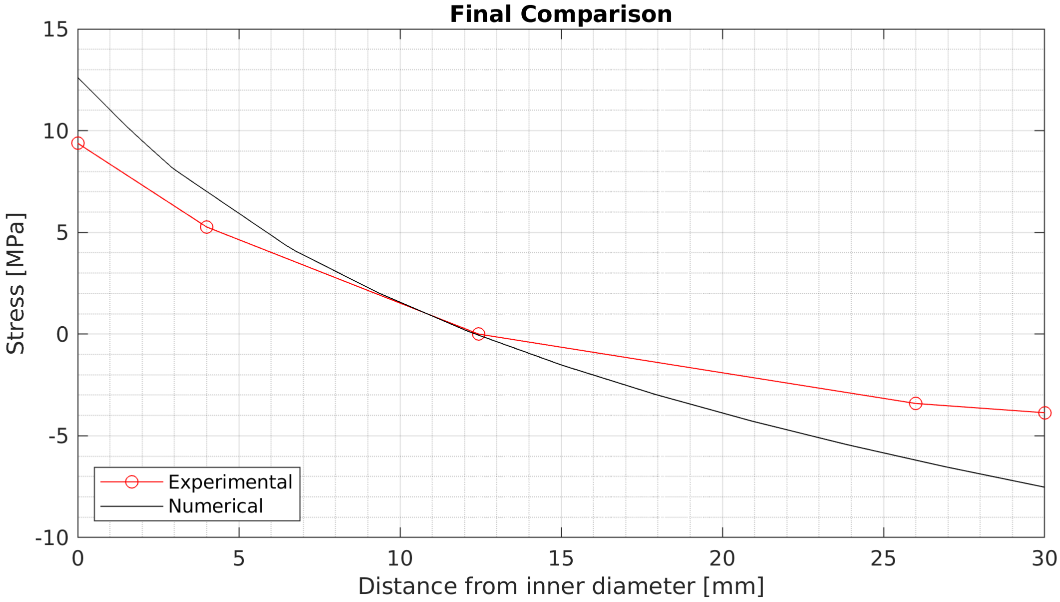


Figure 7: Comparison of normal stresses

Another noticeable fact is, that stress is bigger in inner part of rod, which is kinda expected.

From my point of view, main reason for difference between numerical and experimental solution are poorly choosen material properties for both calculations, as they were took from Ansys Material DB without further thinking, as there wasn't any better source available.

Results could be also impacted by experiment environment, material defects or glue between plexiglass and novodur. Human factor could play it's part too.