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Determination of the necessary geometric parameters of the specimen in Ring-Core method

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Abstract. There are several measuring techniques for determining residual stress which can be divided according to the created damage in to the construction in non-destructive, semi-destructive and destructive ones. One of the most common is semi-destructive hole-drilling method. This paper deals about Ring-Core method which is based on the similar principles. Today, there is no standard for the Ring-Core method, thus it is important to consider various influential factors. One of them are the dimensions of specimen.

Calibration coefficients are determined by finite element (FE) analysis using the commercial software Solidworks. These coefficients are used for residual stress evaluation by incremental method used in Ring-Core method. The influence of different specimen dimensions on the accuracy of the evaluated residual stresses is considered.

Introduction

Like a hole-drilling method, Ring-Core method is a semi-destructive method for determining residual stresses inside the components. This method improves some disadvantages of the hole-drilling method but brings a little more significant specimen destruction.

The Department of applied mechanics and mechatronics at the Faculty of Mechanical Engineering of the Technical University in Košice owns fully automated system MTS3000- Ring-Core from SINT company for determining residual stresses by the Ring-Core method.

a)  b) 

Fig. 1 a) MTS3000- Ring-Core; b) K-RY51-5/350 after milling

Unlike the hole-drilling method, Ring-Core method is based on an annular notch milled around the strain gage rosette, which is attached to the top of the specimen. The inner diameter of milled notch is 14 mm and the outer one is 18 mm. This process creates an isolated core in the specimen, within which the stress balance changes, causing the change of surface strain values. This changes are measured by special strain gage rosette, eg. K-RY51-5/350 from HBM (Fig. 1). The measuring device from SINT company includes high speed hollow mill and stepping motor for precise vertical positioning during each step of milling. To determine the sense, magnitude and direction of residual stresses in dependence on the milled depth, it is important to read the strain gage deformation values in three directions up to maximum depth equals to 5 mm [1].

Incremental method. There are several evaluating procedures for the Ring-Core method. One of them is the incremental method, also called the deformation increments method, which is based on the assumption that each released deformation dε, measured on the top of the core after milling the small depth increment dz, is influenced by the stress in that increment only. Therefore the method is suitable for evaluating the uniform residual stress distribution.

Principal residual stresses σ_1 and σ_2, determining the residual stresses in each depth of released core, are calculated by using calibration coefficients K_1, K_2 and numerical derivations $d\varepsilon_1/dz$ and $d\varepsilon_2/dz$. The derivation of relations for the determination of residual stresses in known principal directions is based on the equations (1)÷(3) [2,3,4]:

$$\frac{d\varepsilon_1}{dz} = \dot{\varepsilon_1}, \frac{d\varepsilon_2}{dz} = \dot{\varepsilon_2}, \tag{1}$$

$$\dot{\varepsilon_1} = \frac{1}{E}(K_1\sigma_1 - \mu K_2\sigma_2), \tag{2}$$

$$\dot{\varepsilon_2} = \frac{1}{E}(K_1\sigma_2 - \mu K_2\sigma_1), \tag{3}$$

where E is Young´s modulus, μ is Poisson´s ratio and $\dot{\varepsilon_1}$, $\dot{\varepsilon_2}$ are numerical derivations of relieved strains in dependence on the step size dz. Subsequently principal residual stresses:

$$\sigma_1 = \frac{E}{K_1^2 - \mu^2 K_2^2} \cdot \left(K_1 \frac{d\varepsilon_1}{dz} + \mu K_2 \frac{d\varepsilon_2}{dz}\right), \tag{4}$$

$$\sigma_2 = \frac{E}{K_1^2 - \mu^2 K_2^2} \cdot \left(K_1 \frac{d\varepsilon_2}{dz} + \mu K_2 \frac{d\varepsilon_1}{dz}\right). \tag{5}$$

Determination of the calibration coefficients by finite element method

The calibration coefficients K_1 and K_2 of the incremental method need to be set for homogenous residual state of stress using the simulation model. The calculation was provided by finite element method (FEM), using software Solidworks 2012. As the simulation model, a cube of sufficiently large parameters was chosen to avoid the influence of the model´s geometrical boundaries on the relieved strains (cube dimensions: 100 mm x 100 mm x 100 mm). The model of strain gage rosette RY51 was also created for reading strain changes across rosettes´ measuring grid surface, which improves the accuracy of the acquired values (Fig. 2).

Material properties used for the simulations: E=210 GPa, μ=0,3. To save the calculation time, only a quarter model of cube was used under these conditions: one cube face was fixed and the opposite one was loaded by a constant uniaxial state of stress σ_1=60 MPa (σ_2=0 MPa). This enabled the simulation of the homogenous residual state of stress inside the whole specimen.

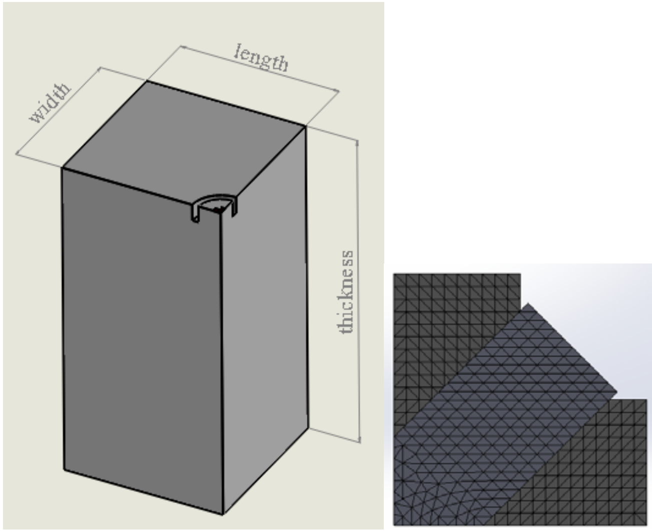


Fig. 2 left: simulation model; right: strain gage rosette mesh

The step size of a milling was constant for all simulations, dz=0,2 mm. After each step the strain values were read, based on which the calibration coefficients K_1 a K_2 were obtained:

(6)

(7)

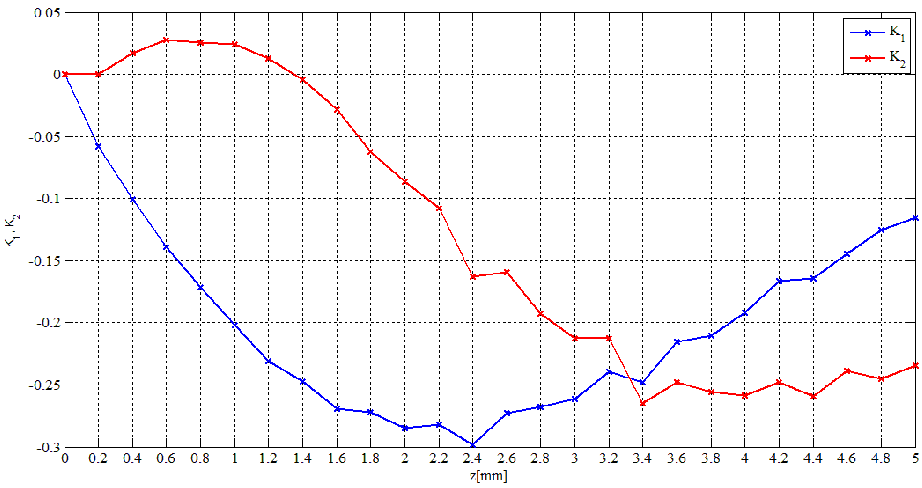


Fig. 3 Functions of universal calibration coefficients K_1 and K_2

It was experimentally verified that these calcualted coefficients could be used for determining any type of homogenous residual state of stress (uniaxial and biaxial), especially for the specific material, the type of the strain gage rosette and the dimensions of the relieved core. Such set of universal calibration coefficients is, however, influenced by the geometric parameters of the specimen. Therefore it is important to set the necessary geometric constraints for their application.

The influence of specimen´s thickness. For the analysis of the thickness dependence on calibration coefficients K_1 and $K_{2,}$ the above-mentioned simulated model was used. The only difference was a thickness dimension changing from 10 mm to 50 mm with the increment 5 mm. Waveform changes resulting residual stresses for specimens with the thickness greater than 50 mm are already negligible. Re-calculations of residual stresses in dependence on the milled depth "z" were provided according to the equations (4), (5), where the functions of the universal calibration coefficients K_1, K_2 defined for the general simulation model were used(*Fig. 3*).

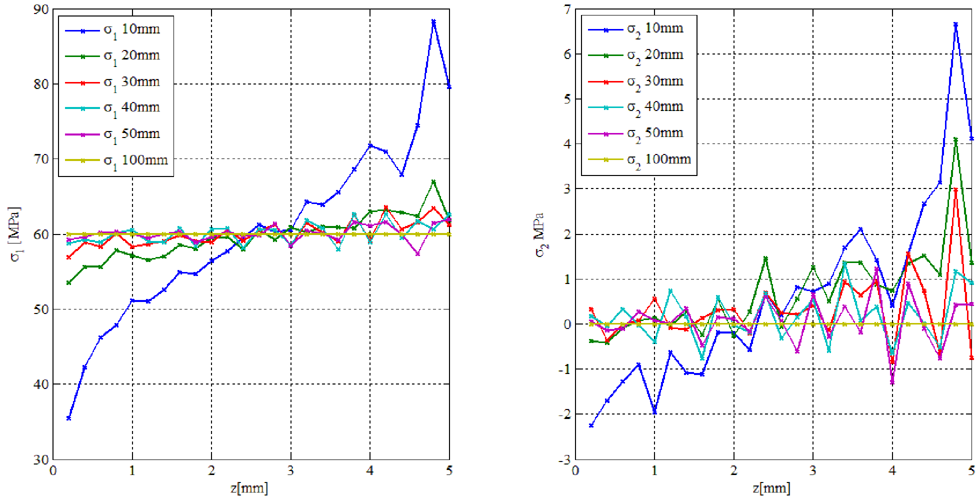


Fig. 4 Calculated residual stresses σ_1 andσ_2 for different thicknesses

According to the waveforms of residual stresses and the re-calculated functions of the calibration coefficients for the specific specimen´s thickness, it is obvious that the minimal specimen´s thickness in Ring-Core method is 30 mm. The residual stresses in specimens thicker than 30 mm, using the device from SINT company could be evaluated by one universal set of calibration coefficients.

The influence of specimen´s width. For the analysis of the width dependence on calibration coefficients K_1 and K_2 the above-mentioned simulated model was used again. Its width was changing from 20 mm to 50 mm with the increment 5 mm. Waveform changes resulting residual stresses for specimens with the width greater than 50 mm are already negligible. Re-calculations of residual stresses using the universal set of calibration coefficients:

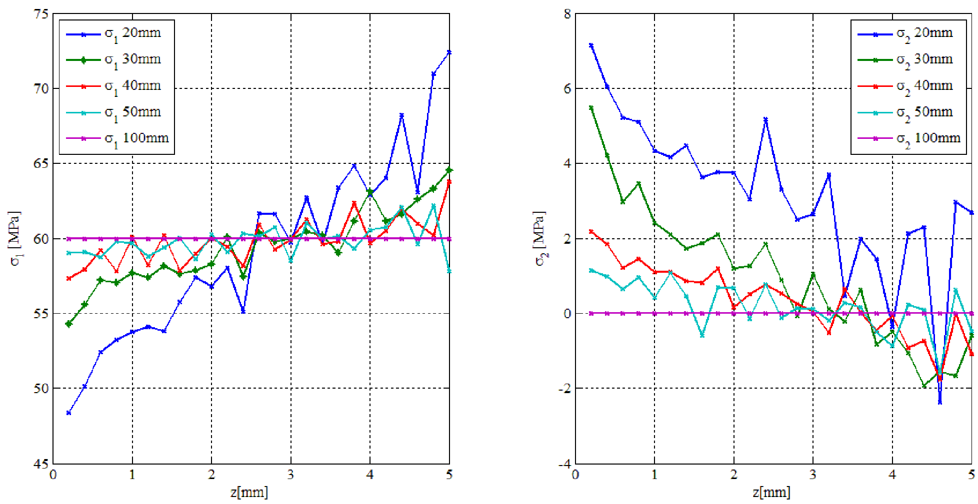


Fig. 5 Calculated residual stresses σ_1 andσ_2 for different widths

By comparing the values of the resulting residual stresses, the minimum width of the testing component under given conditions was set to 40 mm.

The influence of specimen´s length. For the analysis of the length dependence on calibration coefficients K_1 and K_2, the simulated model which length was changing from 20 mm to 50 mm with the increment 5 mm, was used. Waveform changes resulting residual stresses for specimens with the length greater than 50 mm are already negligible. Re-calculated functions of residual stresses using the universal set of calibration coefficients:

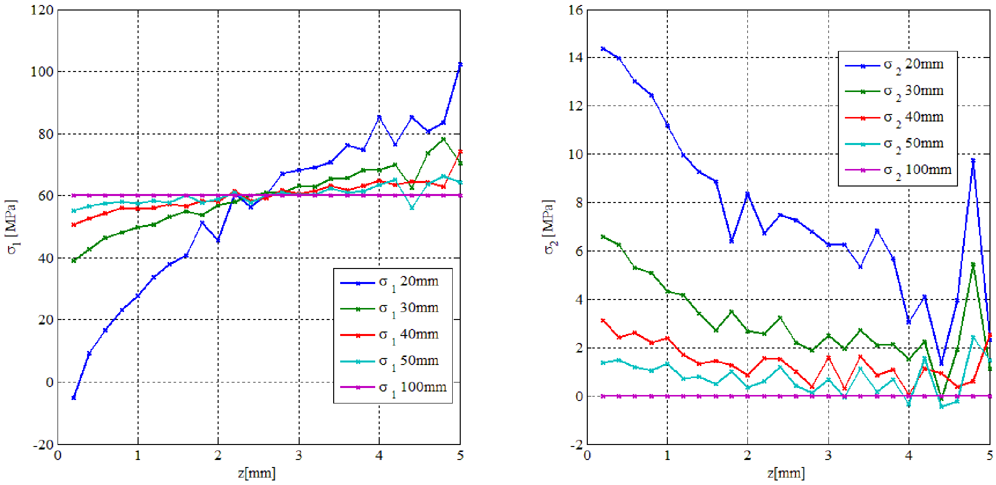


Fig. 6 Calculated residual stresses σ_1 and σ_2 for different lengths

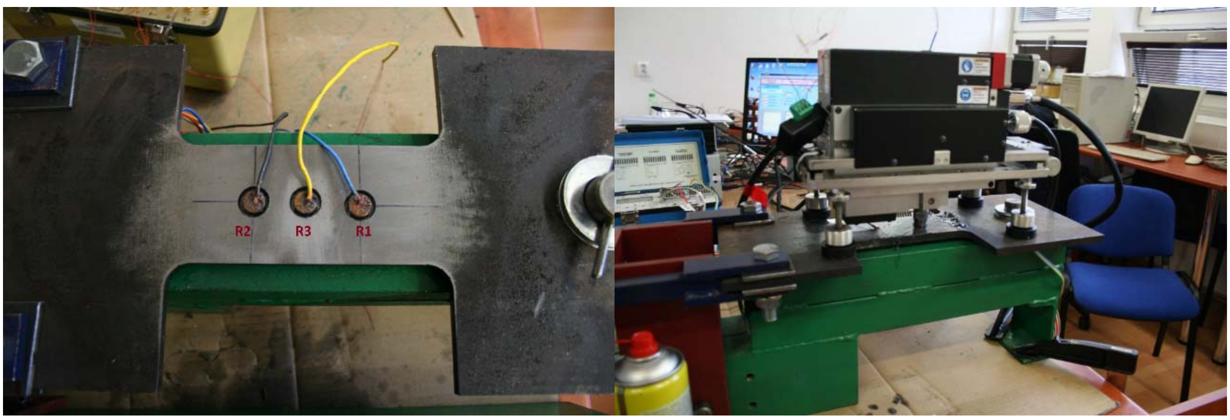
By comparing the values of the resulting residual stresses the minimum length of the testing component, under given conditions, was set to 50 mm.

Experimental verification of the calibration coefficients

The calibration coefficients and their dependence on the specimen´s dimensions obtained from the simulation need to be verified experimentally. For the first verification, the residual stresses evaluation in the thin specimens with the thickness less than 30 mm, was tested. There were 10 mm thin annealed specimen used for this purpose, in which the uniaxial tensile strength σ_1=45 MPa (σ_2=0MPa) was created by the loading device. There were measured strain values in dependence on the milling depth at free different places (R1, R2, R3) using the Ring-Core device (

b)

Fig. *7*).



a) b)

Fig. 7 a) specimen with three strain gage rosettes; b) experimental measuring

The residual stresses re-calculation was done according the adequate calibration coefficents, calculated for the thickness 10 mm by FEM. Experimentally acquired residual stresses were compared to those obtained by the simulation using FEM (Fig. 8).

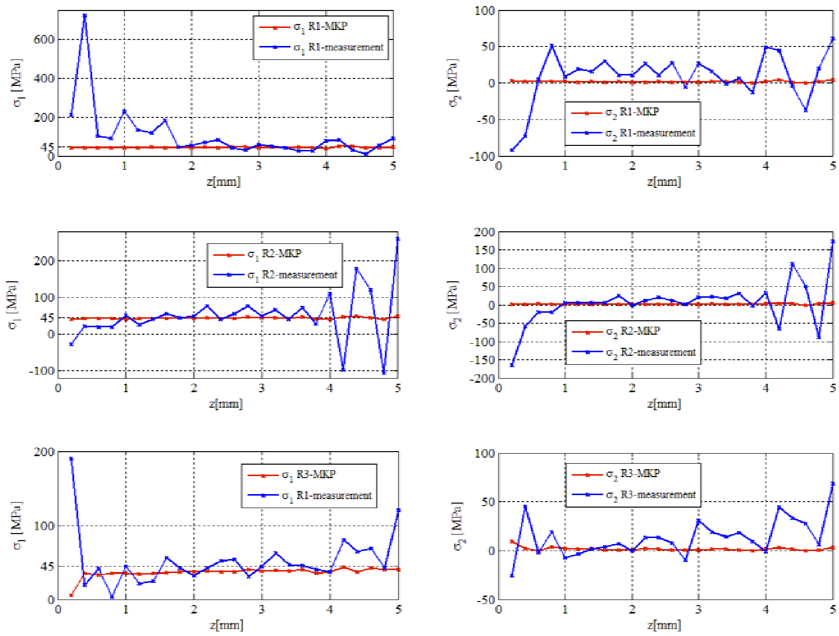


Fig. 8 Comparison of calculated and experimentally acquired residual stresses σ_1 and σ_2 for three strain gage rosettes on the same specimen

Summary

The evaluation of residual stresses by the incremental method using the device MTS3000- Ring-Core could be achieved using one set of calibration coefficients K_1, K_2, for whatever homogenous state of stress, under the condition that tested component is thicker than 30 mm, wider than 40 mm and longer than 50 mm. For the components of smaller dimensions the appropriate set of calibration coefficients has to be used. These results were obtained from the simulation using FEM, and their validity for thin specimens was verified also experimentally. The development of the Ring-Core method continues with the research focused on the milled depth influencing the residual stresses evaluation. Based on the acquired results, it is obvious that the incremental method reaches the most stable waveform of the residual stress in the depth "z" range from 2,5 mm to 3,5 mm. Simultaneously, the development for nonhomogeneous state of stress continues.

Acknowledgements

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