

Verification of Equation for Determining Non-uniform Residual Stresses by FEM

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Abstract Hole-drilling method is one of the most spread methods used for determination of residual stresses and it is regarded as a semi-destructive method. Accuracy of this method depends on the knowledge of calibrating coefficients, which are dependent on geometry of strain gage rosette. These coefficients we can evaluate by FEM. The aim of this work is to verify that the function proposed in the standard ASTM E837 is suitable for the approximation of strains released around drilled hole, at the non-uniform residual stresses.

Keywords: residual stress, hole-drilling method, strain gage rosette, FEM

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1. Introduction

The residual stresses [4] are the stresses that exist in objects without external loading. These stresses are generated by technological processes or by previous loading. In principle all technological processes – rolling, forming and thermal processing etc. generate in produced objects residual stresses. There are numbers of destructive and non-destructive methods which are used for determination of residual stresses. One of them is hole-drilling method. This method is semi-destructive, its principle is based on drilling small hole to the center of strain gage rosette. This process is simple and it is written in standard ASTM E837 [1]. Hole-drilling method is suitable for laboratory conditions and also for working conditions. The test method is applicable to residual stress profile determinations where in-plane stress gradients are small. The stresses may remain approximately constant with depth (“uniform” stresses) or they may vary significantly with depth (“non-uniform” stresses). The measured workpiece may be “thin” with thickness much less than the diameter of the drilled hole or “thick” with thickness much greater than the diameter of the drilled

hole. Only uniform stress measurements are specified for thin workpieces, while both uniform and non-uniform stress measurements are specified for thick workpieces.

For determination of residual stresses by hole-drilling method we have to know coefficients \bar{A} and \bar{B} (or \bar{a} and \bar{b}). Knowledge and accuracy of these coefficients is very important for the calculation of residual stresses.

The aim of this work is to verify that the function (1) proposed in the standard ASTM E837 is suitable for the approximation of strains released around drilled hole, at the non-uniform residual stresses [2,3,5].

$$\varepsilon_r = (\bar{A} + \bar{B} \cos 2\beta) \sigma_x + (\bar{A} - \bar{B} \cos 2\beta) \sigma_y \quad (1)$$

Where:

ε_r – relieved strain measured by a radially aligned strain gage centered at P,

\bar{A} , \bar{B} – calibration constants,

σ_x – stresses in x direction,

σ_y – stresses in y direction,

β – angle measured clockwise from the direction of gage 1.

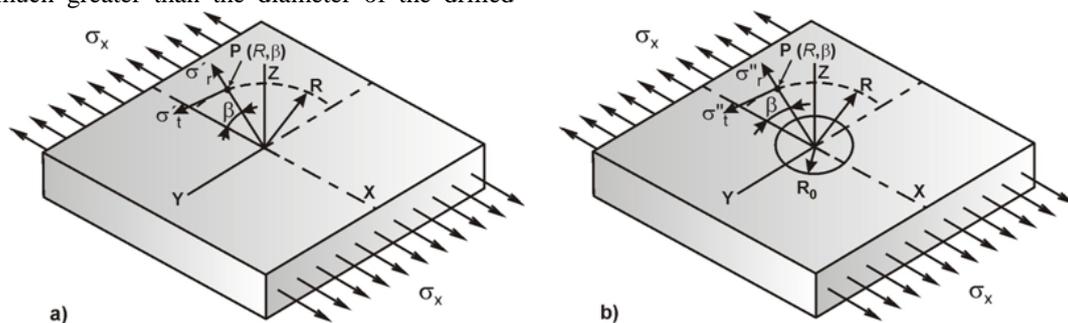


Figure 1. Stresses in point P before and after drilling

The shape of this function accurately describes the deformation around drilled hole (Figure 1). Coefficients \bar{A} and \bar{B} used in equation (1) are defined according to the recommendations of the standard ASTM E837.

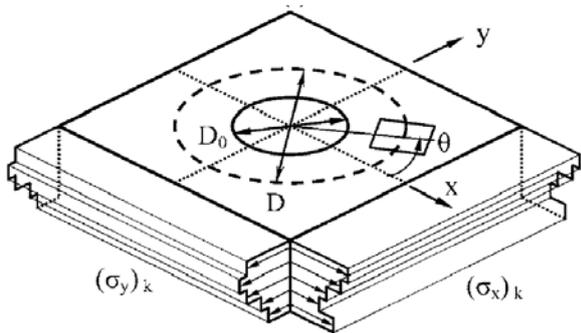


Figure 2. Hole geometry and residual stresses for non-uniform stresses

2. Modeling of Specimen with Strain Gage Rosette

For modeling was used software COSMOS / M. Shaped sample was modeled as a rectangular plate (Figure 3). Due to the symmetry was modeled only one quarter of the plate what significantly reduces computation time [6].

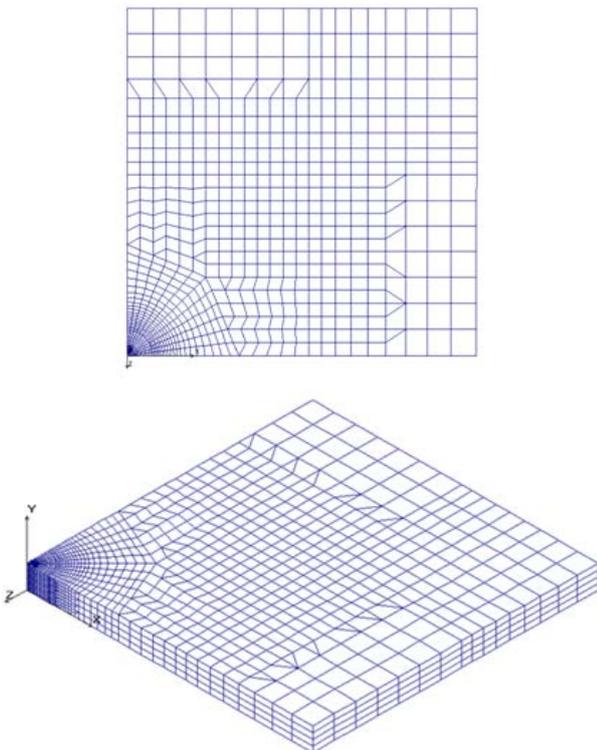


Figure 3. Finite element model

Individual strain gages were modeled using elements (Truss2D), which allowed easy retrieval of strains. After that the elements of the strain gage model were applied to the finite elements grid model of the plate (Solid8). Modulus of elasticity of the elements is $E=1.10^6$ MPa. We used strain gage rosette of type B according to the standard ASTM E837 (Figure 4) – strain gage 1 is identified with the x direction and strain gage 3 is identified with the y direction (Figure 5).

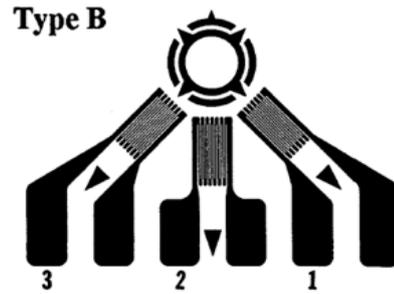


Figure 4. Strain gage rosette of type B

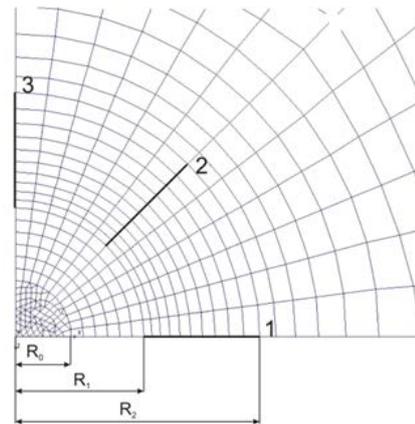


Figure 5. Model of the strain gage rosette

Dimensions of used strain gage rosette:
 Min $D_0 = 1.52$ mm, $R_1 = 1.77$ mm, $D = 5.13$ mm, Max $D_0 = 2.54$ mm, $R_2 = 3.36$ mm

We chose diameter $D_0 = 2 * R_0 = 1.539$ mm which is in our flowing interval.

For modeling of the stress field, which is varying in different depths, was used model with simulation of bending, according to Figure 6.

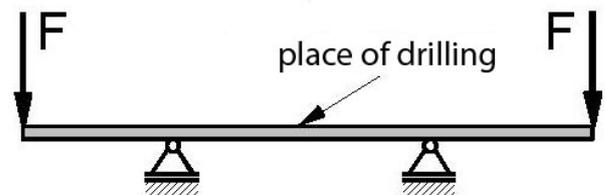


Figure 6. Bending beam

The thickness Z of the sample was selected $Z = 0,8.D = 0,8.5,13 = 4,104$ mm which is in according to ASTM E837 considered as a medium sample. The entire thickness of the sample was divided into 32 equal sized sections – one section will have a thickness $Z_i = \frac{Z}{32} = 0.12825$ mm (Figure 7).

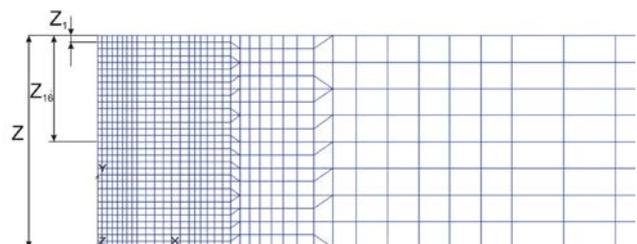


Figure 7. Layers of FE model

Boundary conditions and loading method is shown in Figure 8.

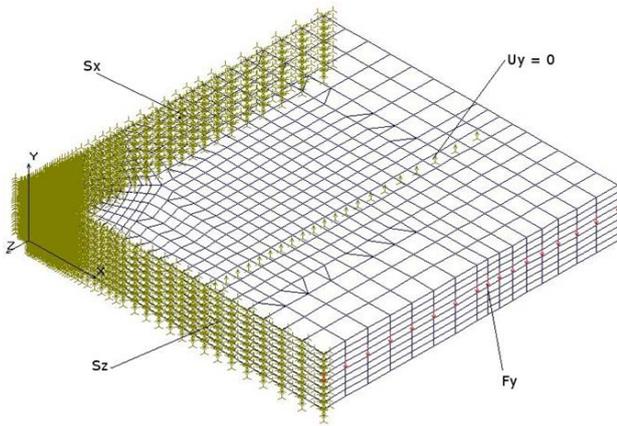


Figure 8. Boundary conditions

Stress field σ_x before drilling of the hole is shown in Figure 9.

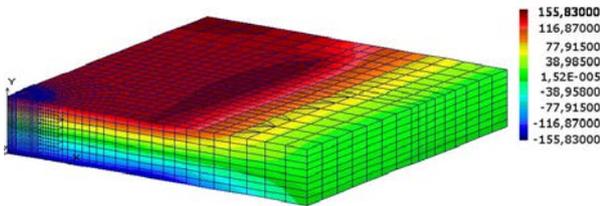


Figure 9. Stress field σ_x before drilling of the hole

For exact determination of the state of strains around the hole is necessary to extend the model of strain gage rosette as shown in Figure 10.

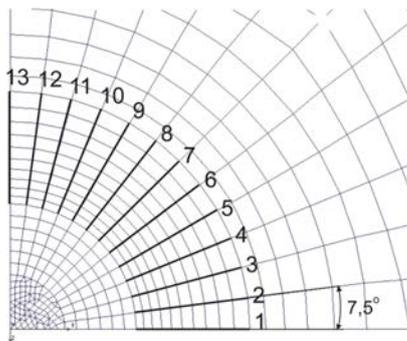


Figure 10. Arrangement of the strain gages

By simulation of progressive drilling and determining of strains in individual strain gages we obtain searched strains. Figure 11 shows strains after drilling of the first layer.

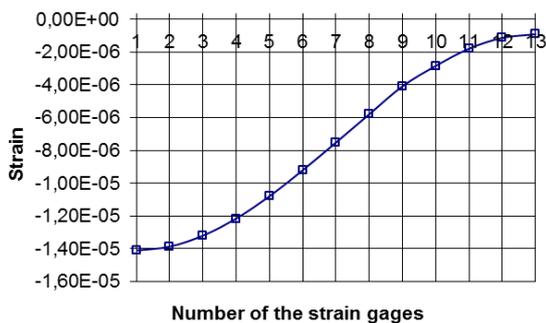


Figure 11. Strain after drilling of the first layer

This curve is similar as the shape of the curve in the stress graph for the equal distribution of stresses through the thickness of the sample (Figure 12) [5].

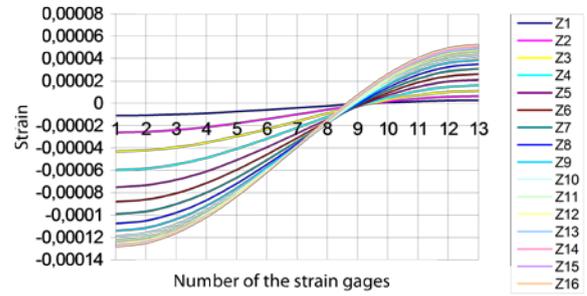


Figure 12. Relieved strains of different depth increments for uniform residual stresses

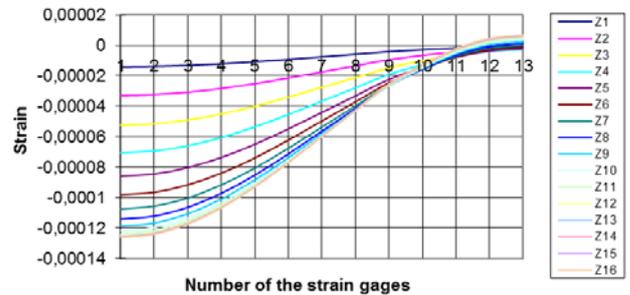


Figure 13. Relieved strains of different depth increments for non-uniform residual stresses

We can assume that the function (1) can also be used in determining the stress that is variable over the depth of drilling hole. If we drill progressively more layers we find that from the 14th layer the curve is changing only very little. This means that the strain is relaxed. This fact can be confirmed by Figure 13.

3. Conclusion

Knowledge of residual stresses is important for example for accurate determination of residual lifespan or for reinforcing components. Removal of residual stresses can be very expensive and sometimes it is easier to determine their influence on the load capacity of the element. In most cases is difficult to determine residual stresses analytically. For this reason experimental methods for the determination of residual stress are still very important.

The findings of this paper are incorporated into the software MEZVYNA [7] used to determine residual stresses by hole-drilling method, which is developed at our department.

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