Method for Calculating Residual Strains and Visual Diagnostics by a Specialized Software System

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Abstract – **Abstract - In this article the authors suggest specialized software system, which revises roentgenografic method for calculation of residual strains in metals with poly-crystal grating, by applying a roentgenostructural analysis on a complex strained condition. The character of this strained condition has a significant influence on the conduct of the metal article in the conditions of exploitation. The definition of the macro tensions is brought to a precise definition of the periods of the crystal grating and recalculating the received values deformations and tensions.**

Keyword – **specialized software system, method for calculation.**

I. Introduction

The roentgenographical method for definition of the macro tensions is based on the fact that by the presence of a macro-strained condition the intra-surface distances are changing, which has effect on the situation of the diffraction lines. Consequently The definition of the macro tensions is brought to a precise definition of the periods of the crystal grating and recalculating the received values deformations and tensions.[1,2,3]

II. Experimental part

The deformation of the crystal grating can be expressed through the intra-surface distance:

$$\varepsilon = (d - d_0)/d_0 \qquad (1)$$

Hook`s law,

where: d – intra-surface distance of a material with tension; d_0 – intra-surface distance of a material in non-strained condition.

Dependencies by a different strained condition:

$$\Delta\theta = \Delta d/d \cdot tg(\theta_0) \qquad (2)$$

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Equation of Woolf-Brek;

$$\sigma = E/\mu \cdot \cot g(\theta_0) \cdot \Delta\theta; \qquad (3)$$

μ – Plank constant;

Δθ – changing of the angle of the reflected roentgen

wave;

θ_0 – base angle.

From the equation (3) it is clear, that in order to define the tensions by a roentgenographical method we have to find θ_0 и Δθ.

For carrying out this experiment it is needed the space angles, between the roentgen ray and the surface of the model to be defined:

φ – placed in a plain, parallel of the surface of the model and connects the main strain σ_1 and projection of the roentgen ray on the surface of the model.

Ψ – This is an angle between σ_3 and the direction of the roentgen ray.For definition of the tensor of the deformations and the strains man has to do the following:

- Roentgenograms by azimuthally angles φ = 0° (in the direction of the grinding) and several values for ψ (0°> ψ>90°) and φ = 45° и 90° are being recorded;
- The angles θ(φψ) are being defined and calculated d(φψ);
- Graphical dependencies $d\theta_{\varphi\psi}$) - sin2ψ by φ = 0°, 45° and 90°, which are straight functions, are being build.

The components ε_{ij} of the deformations are defined through the tangencies of the inclination according to the method Dolle-Hauk.

$$\begin{aligned} tg(1) &= d_0(\varepsilon_{11} - \varepsilon_{33}) \\ tg(2) &= d_0(1/2\varepsilon_{11} + 1/2\varepsilon_{22} - \varepsilon_{33} + \varepsilon_{12}) \\ tg(3) &= d_0(\varepsilon_{22} - \varepsilon_{33}) \\ tg(4) &= d_0\varepsilon_{33} \\ tg(5) &= d_0\frac{1}{\sqrt{2}}(\varepsilon_{13} - \varepsilon_{23}) \\ tg(6) &= d_0\varepsilon_{23} \end{aligned} \qquad (4)$$

The value of a_1,φ = 0 does not depend on φ and it is equal to $d_0*\varepsilon_{33}$. Through ε_j we can get the tensor of the deformations:

$$\begin{matrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{matrix} \quad (5)$$

and by the general Hook`s Law the components σij of the tensor of the strain can be calculated:

$$\sigma_{ij} = 2/(S_2)\left[\varepsilon_{ij} - \delta_{ij} S_1(\varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33})/(S_2/(2) + 3S_1)\right]$$

$$\begin{matrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{matrix} \quad (6)$$

If the components σ_{13} have values above the mistake of the experiment, this means that the surface of the main strains σ_1, σ_2 is inclined towards the surface of the model in the following angle:

$$\Delta\Psi = \frac{1}{2} arctg\left(-\frac{2\sigma_{13}}{\sigma_{13} - \sigma_{31}}\right) \quad (7)$$

Calculation of the main strains σ_1, σ_2, σ_3 in this case is done by the following equations:

$$\begin{aligned} \sigma_1 &= (\sigma_{11} + \sigma_{33}) + r_\sigma \\ \sigma_2 &= \sigma_{22} \\ \sigma_3 &= (\sigma_{11} + \sigma_{33}) - r_\sigma \end{aligned} \quad (8)$$

where:

$$\begin{aligned} r_\sigma &= \sqrt{\frac{2(\sigma_{33} - \sigma_{11})}{4 + \sigma_{13}}} \\ tg(7) &= d_0(\varepsilon_{11} - \varepsilon_{33}) \\ tg(8) &= d_0(\varepsilon_{22} - \varepsilon_{33}) \end{aligned}$$

From here

$$\begin{aligned} \varepsilon_{11} &= tg(7)/d_0 + \varepsilon_{33} \\ \varepsilon_{22} &= tg(8)/d_0 + \varepsilon_{33} \\ \varepsilon_{33} &= (d_\varphi = 0,\ \Psi = 0 - d_0)/d_0 \end{aligned} \quad (9)$$

$$\begin{matrix} \varepsilon_{11} & 0 & 0 \\ 0 & \varepsilon_{22} & 0 \\ 0 & 0 & \varepsilon_{33} \end{matrix}$$

The tensor of the strain is being calculated by the formula:

$$\sigma_{ii} = \frac{2}{S_2}\left[\varepsilon_{ii} - \frac{S_1(\varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33})}{\frac{S_2}{2} + 3S_1}\right] \quad (10)$$

Using the center of the weight we can receive values of the diffraction angles.

$$\begin{aligned} a_{\varphi\psi} &= (d_{\varphi\psi} > 0 + d_{\varphi\psi} < 0)/2 \\ a_{\varphi\psi} &= (d_{\varphi\psi} > 0 - d_{\varphi\psi} < 0)/2 \end{aligned}$$

With the already calculated values for a_1 and a_2, for all the combinations φ(ψ) the grafics for every φ are beeing build:

$$\begin{aligned} a_1\varphi &= 0(\sin 2\psi) \\ a_1\varphi &= 45(\sin 2\psi) \\ a_1\varphi &= 90(\sin 2\psi) \\ a_2\varphi &= 0(\sin|2\psi|) \\ a_2\varphi &= 45(\sin|2\psi|) \\ a_2\varphi &= 90(\sin|2\psi|) \end{aligned} \quad (11)$$

To define the exact function of the separate graphics the method of the least squares is being used. [1, 2]

$$f(x) = a + b \cdot x \quad (12)$$

– equation of interpolation function

$$\begin{aligned} aM + b\Sigma_1 Mx_i &= \Sigma_1 My_i \\ a\Sigma_1 Mx_i + b\Sigma_1 Mx_{i2} &= \Sigma_1 Mx_i y_i \end{aligned}$$

where:

(x_i, y_i) – coordinates of the experimental points;

M – number of points.

$$\begin{aligned} a &= \frac{\Sigma_1 My_i \cdot \Sigma_1 Mx_{i2} \cdot \Sigma_1 Mx_i y_i}{M\Sigma_1 Mx_{i2} - 2(\Sigma_1 Mx_i)} \\ b &= \frac{M\Sigma_1 Mx_i y_i - \Sigma_1 Mx_i \cdot \Sigma_1 My_i}{M\Sigma_1 Mx_{i2} - 2(\Sigma_1 Mx_i)} \\ b &= tg\alpha \end{aligned} \quad (13)$$

where: α – slope angle of the straight line.

Into the methods, which are used it is necessary the angle factors of all the graphics to be found (14). Than through them the deformations are being found: [1, 2, 3]

$$\begin{aligned} \varepsilon_{33} &= (d\varphi = 0,\ \psi = 0 - d_0)/d_0 \\ \varepsilon_{11} &= tg(1)/d_0 + \varepsilon_{33} \\ \varepsilon_{13} &= tg(4)/d_0 \\ \varepsilon_{12} &= tg(2)/d_0 - \varepsilon_{11}/2 - \varepsilon_{22}/2 + \varepsilon_{33} \\ \varepsilon_{22} &= tg(3)/d_0 + \varepsilon_{33} \\ \varepsilon_{23} &= tg(6)/d_0 \\ \varepsilon_{21} &= \varepsilon_{12} \\ \varepsilon_{31} &= \varepsilon_{13} \\ \varepsilon_{32} &= \varepsilon_{23} \end{aligned} \quad (14)$$

$$\sigma_{ij} = \frac{2}{S_2}\left[\varepsilon_{ij} + \frac{S_1(\varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33})}{S_2/2 + 3S_1}\right] \quad (15)$$

$i = 1, 2, 3;\ j = 1, 2, 3$

tensor of the deformations:

$$[\varepsilon] = \begin{matrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{matrix} \qquad (16)$$

tensor of the strain:

$$[\sigma] = \begin{matrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{matrix}$$

Calculation the slope of the surfaces of the main tensions:

$$\Delta\Psi\sigma = \frac{1}{2} arctg\left[-\frac{2\sigma_{13}}{\sigma_{11}-\sigma_{33}}\right] \qquad (17)$$

Definition of the main deformations and tensions:

$$r_\varepsilon = \sqrt{\frac{2(\varepsilon_{33}-\varepsilon_{11})}{(4)+\varepsilon_{13}2}}$$
$$r_\sigma = \sqrt{\frac{2(\sigma_{33}-\sigma_{11})}{(4)+\sigma_{13}2}} \qquad (18)$$

$$\begin{aligned} \varepsilon_1 &= (\varepsilon_{11}+\varepsilon_{33})/2 + r_\varepsilon \\ \varepsilon_2 &= \varepsilon_{22} \\ \varepsilon_3 &= (\varepsilon_{11}+\varepsilon_{33})/2 - r_\varepsilon \\ \sigma_1 &= (\sigma_{11}+\sigma_{33})/2 + r_\varepsilon \\ \sigma_2 &= \sigma_{22} \\ \sigma_3 &= (\sigma_{11}+\sigma_{33})/2 - r_\varepsilon \end{aligned} \qquad (19)$$

$$[\varepsilon] = \begin{matrix} \varepsilon_1 & 0 & 0 \\ 0 & \varepsilon_2 & 0 \\ 0 & 0 & \varepsilon_3 \end{matrix} \qquad (20)$$

$$[\sigma] = \begin{matrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{matrix}$$

III. CHOICE OF SOFTWARE PRODUCTS FOR REALIZATION.

A. Visual Basic .NET 2003

The used language for projecting and programming of the current application is Visual Basic .NET. The user`s interface is developed in Visual Basic.

B. Visual Basic .NET Power Pack

Visual Basic.NET Power Pack consists of seven controls, written on Visual Basic .NET 2003.

In the current application is used ImageButton, there you can insert picture and text. It implements IButtonControl and in this way it can be AcceptButton or CancelButton of the form. [4,5]

In order to use VB Power Pack, in the project has been made a link to VbPowerPack.dll.

In the current computer system InnoSetup is used for creating of the installator of the application. [3, 4, 5]

C. Macromedia RoboHelp

Macromedia RoboHelp is an application for creating Help systems and documents for desktop and web based applications, including.NET.

Some main advantages of RoboHelp are:

- Work in preferred from the user editor – we use the built in RoboHelp HTML editors, as Dreamweaver, Frontpage or Microsoft Word;
- Pasting of content into an HTML documents, Microsoft Word, Adobe PageMaker, PDF documents, XML documents or existing HELP projects.
- Easy crating of context-sensible assistant;
- Generating of every popular help format - FlashHelp, WebHelp, Microsoft HTML Help, WinHelp, JavaHelp, Oracle Help for Java and XML.
- Creating of HELP systems, working with every platform and browser;
- Creating a great number of versions for the existing HELP system.

In the current development RoboHelp is used for creating the Assistant to the application.[5]

D. Macromedia Captivate

Macromedia Captivate is a product for creating an interactive simulations and software demonstrations in Macromedia Flash format. The advantages of Captivate are:[3,4,5]

- It takes hold of everything, which is being shown on the screen even web based applications with or without parallel audio;
- Automatically adding interactivity during recording;
- Possibility for publishing in a great number of formats for distribution;
- Possibility for changing or deleting the trajectory of movement of the mouse;
- Automatically creating titles for every step.

For testing the present program system there were used external and structure tests aiming finding and correcting of the made mistakes. The structural method for testing is based on the text of the program module. For that purpose the following is needed:

- Program separation of the module and definition of its information connection to the system. If other modules are being evoked it is necessary they to be structurally tested or simulators to be put on their place;
- In the program text the structure defining operators need to be found and numbered;
- Depending on the type and the semantics of the operators, they have to be represented into a conditional IF – structures;
- The operators between two adjoining IF are representing a straight line section. It can be without operators. If a feedback connection is present, causing multiple implementation of the straight line section, then a cyclic section is found in the program module;
- IF operators are interpreted as peaks of the structural graph, and the linear sections are interpreted as its arcs;
- The structural graph is represented with its matrix of the connections as a list structure;
- The structural graph of the program module is decomposing as a sequence of linear and deposed cyclic sections.

In order to fulfill this test the debugger of Visual Studio NET and its Watch module are used. The breaking points are placed. The values accepted by a given variable are traced and in which branch of the graph it goes. The testing was performed in the “up-down” direction and all the arcs were enveloped.

There were no mistakes found during the conduction of the test. The graphical results visualize the distribution of the residual strains in depth of the examined sample.

V. CONCLUSION

In this stage the experiment was successfully concluded.

The method for calculating residual strains through computer roentgen-structural analysis in complex strain condition allows:

1. Automated calculation of the parameters, needed for calculation of the residue strains in depths;
2. Presentation of the experimental results in digital and graphical mode – convenient for analyze;
3. The method of „ψ – splitting” allows the special features of the deformed and strained condition of the construction materials after grinding to be determined and analyzed;
4. The usage of the method Dolle-Hauk allows the following to be determined: the full tensors of the deformations and strains, the values of the main deformations and strains in the grinded layer, as well as the inclination of the main axes of the ellipsoid of the deformations and respectively of the strains, and as a whole the distribution of the residual strains in depth;
5. The results of the experimental examination in near to the practice conditions are showing high exactness and reliability of the system;
6. In economical aspect, this method is saving the usage of specialized mathematical software as MathCad (by Mathsoft) и Mathlab (by Mathworks) and it is many times cheaper comparing to this software.

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