Tensometric captor to determine the residual stress and calibration of the finite element method

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Abstract: - The present work is presenting a tensometric captor used for determining the residual stress using “Blind hole drilling” method. This captor represents a practical and economical solution by replacing the strain gauge rosette with three elastic strain gauges blade captors, which were provided with a tensometric bridge each. The correspondence between the movement of the point on the sample’s surface and the deformation is carried out with the finite element method by validating the results with the movement classical measurements.

Key-Words: - “Blind hole drilling” method, strain gauges blade captors.

1 Introduction
Make a hole in a body containing residual stresses, relaxes tension there, because any free surface normal blood must necessarily be zero. Removing normal tension at the edge of the hole reducing tensions in the vicinity of the surrounding region, causing local deformations to be amended accordingly. Calculations are obtained by measuring the deflection produced by relaxing tension modification. Based on these observations (Fig.1), American Society for Testing and Materials (ASTM E 837) has developed the “Blind Hole Drilling” method, one of the most common technical methods of measuring residual tensions. The method involves installing a rosette of strain gauges marks (Fig.2) and practicing a shallow holes on the surface and measuring the change in the state of deformation in the immediate vicinity of the hole. From experimental data obtained can be calculated residual tensions relaxed.

Method is considered "semidistructive" (in most cases typical hole 1/16 "or 1/8" deep and in diameter to significantly affect the structural integrity of the part tested, if necessary, the hole can be covered after measuring). Pack deformations at the point P (Fig.3) after a hole are the main functions of local tensions \( \sigma_p \) and \( \sigma_q \) and the geometrical relationship between the point and the hole and the point and the principal axes [1]. Radial and tangential deformations normal (Fig.4) sinu varies along a circle of radius R and can be expressed in general that (1.a) and (1.b):

\[
\varepsilon_r = \sigma_p \left( A + B \cos 2\alpha \right) \quad (1.a)
\]

\[
\varepsilon_\theta = \sigma_p \left( -A + C \cos 2\alpha \right) \quad (1.b)
\]

\[
A = -\frac{1 + \nu}{2E} \left( \frac{1}{r^2} \right) \quad (2)
\]

\[
B = -\frac{1 + \nu}{2E} \left[ \left( \frac{4}{1 + \nu} \right) \frac{1}{r^2} - \frac{3}{r^4} \right] \quad (3)
\]

\[
C = -\frac{1 + \nu}{2E} \left[ \left( \frac{4\nu}{1 + \nu} \right) \frac{1}{r^2} + \frac{3}{r^4} \right] \quad (4)
\]

where:
\( \varepsilon_r, \varepsilon_\theta \) = tangential and radial deformation that point P;
\( r = R/R_0 \) dimensionless radius of the point P to the center hole; \( E, \nu \) = Young and Poison modulus of the material.
2 Strain gauges blade captor

This work presents a practical and economical alternative method for implementing "Blind Hole Drilling", to determine the residual tensions by replacing strain gauges rosettes of brands with a three strain gauges blade captor.

Strain gauges blade captors are elastic blade that are glued half bridge strain gauges.

Strain gauges blade captors (Fig.5) are required bending recesses at the opposite end by means of anchor points in three points located at the radius and angles calculated from the center hole to be given in the play area.

In this configuration, strain gauges blade captors measured displacements and deformations not play the point on the surface tension relaxation of existing waste.

Figure 6 is presented geometrical dimensions of the strain gauges blade captor and position marks.

The device with three strain gauges blade captors are positioned and fastened to the surface in the area where the play is to be conducted to determine the residual tension.

By running a hole in the center between the tops of the anchor blade strain gauges captors residual tensions in the play relax causing deformation of the surface.

The three captured strain gauges blade captors measured the movements of points on the surface size of the piece and presents these values on the display of electronic strain-measuring instrument as bending deformation of elastic fibers slide.

3 Calibration by finite element method to strain gauges blade captors

The question is to determine a correlation between movements of surface points calculated at the radius from the center hole and deformation.

This correspondence is done by modeling the strain gauges blade captors finite element method (FEM) and validate the results by conventional measurements of displacement.

Modeling starts with defining geometrical volumes (Fig.7) and material properties.

After the finite element meshing operation starts solution processor is blocked degrees of freedom corresponding constraint and displacements values apply to nodes in the application plan, figure 8.
By launching postprocessor to obtain images of the structure (deformed and non-deformed) and tabulated values of nodal deformations, figure 9.

After launching postprocessor selecting two nodes from the blade area at the center areas of trade arrangement strain gauges.

From the tables provided by the postprocessor are marked deformations nodal values for these two knots for a range of values of displacement brought the load end slide.

In Table 1 are given values of strain for selected points on strain gauges blade captors measured with an electronic strain measuring instrument and calculated by FEM modeling.

<table>
<thead>
<tr>
<th>Displacement (d) at end of blade captor [mm]</th>
<th>Strain (ε) measured at the electronic strain-measuring instrument [µm/m]</th>
<th>Strain calculated by FEM [µm/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>4.999</td>
<td>4.9860</td>
</tr>
<tr>
<td>0.01</td>
<td>10.453</td>
<td>10.4408</td>
</tr>
<tr>
<td>0.015</td>
<td>16.362</td>
<td>16.3648</td>
</tr>
<tr>
<td>0.02</td>
<td>20.452</td>
<td>20.4540</td>
</tr>
<tr>
<td>0.025</td>
<td>26.361</td>
<td>26.3360</td>
</tr>
<tr>
<td>0.03</td>
<td>33.178</td>
<td>33.1780</td>
</tr>
</tbody>
</table>

From the graphical representation of these values (Fig.10) follows a very good approximation of results.

The experimental setup shown in Figure 11 determine the correlation that exists between the movement end strain gauges blade captors produced by a micrometric screw and deformation values read on the electronic strain-measuring instrument.

4 Measurements made with strain gauges blade captors

Strain gauges blade captors is used to measure the state of biaxial residual stresses in three zones (weld seam, ZIT and base material) of a head-to-head welded joint head-to-head.

They were joined by two plates of thickness 12mm 10TNC180 by MIG welding.

Measurement was carried out incrementally by dividing the total depth seven equal size of the hole. Hole depth is equal to its diameter (D=Z=3.5mm).

The values of deformations in three directions for each increment of depth are given in Table 2.

<table>
<thead>
<tr>
<th>Z [mm]</th>
<th>ε₁ [µm/m]</th>
<th>ε₂ [µm/m]</th>
<th>ε₃ [µm/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>20</td>
<td>33</td>
<td>12</td>
</tr>
<tr>
<td>1.0</td>
<td>10</td>
<td>63</td>
<td>24</td>
</tr>
<tr>
<td>1.6</td>
<td>5</td>
<td>83</td>
<td>24</td>
</tr>
<tr>
<td>2.0</td>
<td>7</td>
<td>80</td>
<td>28</td>
</tr>
<tr>
<td>2.6</td>
<td>5</td>
<td>83</td>
<td>28</td>
</tr>
<tr>
<td>3.0</td>
<td>5</td>
<td>73</td>
<td>16</td>
</tr>
<tr>
<td>3.5</td>
<td>0</td>
<td>76</td>
<td>8</td>
</tr>
</tbody>
</table>

Fig.9. The appearance of deformed and non-deformed structure (as nodal deformation axis OX)

Fig.10. Change in strain with displacement

Fig.11. Experimental setup to determine the displacement and deformation correspondence

Table 1

Table 2
5 Conclusion

It presented a practical and economic alternative for applying the method of determining the residual stress "Blind Hole Drilling" method by replacing the strain gauges rosettes with a strain gauges blade captors. Correspondence between points surface displacement and strain is done by FEM modeling the strain gauges transducer. One can notice a very good approximation of the values obtained from determinations experimental deformation those calculated by finite element method. The validation is done by conducting classical measurements of strain. The strain gauges transducer incremental measurements were made at three points of deformations of welded combination: weld seam, ZIT and MB. With these values were calculated principals stress values.

References: