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Proposal of Methodology for Determination of Stresses around Groove by Photo Stress Method

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Abstract The aim of the paper is to propose a new methodology for verifying residual and operational stresses, determined by the drilling method. The newly proposed methodology will be based on the use of optical methods for total surface deformations and stress analysis through optically sensitive material applied to the surface of the object being investigated.

Keywords: *residual stresses, ring-core method, photo stress*

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1. Introduction

The determination of the causes or the prediction of the occurrence of the defects of the supporting elements of the structures is still a highly current topic related to the assessment of the lifetime of structures, machines, equipment and the like. It should be emphasized that many disturbances in the operation of parts of structures or machines are not only a consequence of load-induced stresses but also due to residual stresses. Residual stresses also occur in unloaded constructions. The risk of their occurrence is mainly related to the fact that they are superimposed on operating stresses, which can significantly affect the life of machines and equipment. For this reason, for prediction of fault, these stresses need to be known and quantified. At present, for example, the drilling method is used to determine residual stresses in the material.

2. Residual Stress, Analysis of the Blind Hole Created by the Drilling Methods

Residual stresses are stresses in machine components, structures, or mechanical systems that are in the elements after the load process, even if no external force is already applied to the component or system. They occur, for example, in forming, casting, rolling, hardening, machining, welding, heat treatment or improper cooling of materials. Other sources of these stresses include, for example, repair of construction, montage and operation of equipment, overloading and the like [1].

In Figure 1 is a view of beams with cracks. To assess the causes of cracks, residual stresses should be determined.

Residual stresses have, in the vast majority of cases, adverse effects resulting in to create an infringement of carrier elements. They are able to overcome the stress corrosion, fatigue effects and are difficult to overcome. Residual stresses should be quantified already during the operation of the device in order to determine their effect on the required functionality (lifetime) of the component [2].

Figure 1. Cracks on beams

Until recently, there were no available methods of measuring them without disturbing the integrity of the structure, and this represented a risk of ignorance of the intrinsic behaviour of the material. Residual stresses cannot be measured by conventional experimental analysis, as the strain detector is insensitive to the load history of the treated part and detects the change and strain size after until installation of the sensor. When residual stresses are detected, the stresses in the structure must be released in the prescribed manner with the help of an applied transducer (strain-gage rosette) at the measuring location that registers the change of strain. Residual stresses are then determined from the measured strains. In the past, these cases have been dealt with in a destructive way, either by cutting or removing the surface layer of the material. Today more sophisticated ways of detecting residual stresses are used. Among them we can include X-ray diffraction measurement, which represents a non-destructive method of detecting residual stresses, but it is possible to detect deformations only in a very thin layer. Other non-destructive methods are e.g. electromagnetic or ultrasonic methods. Residual stresses deserve great attention in the future because they are usually undesirable, difficult to detect and removal is economically demanding [3].

They are useful for determining residual stresses on machine components surfaces. The principle of drilling methods is to determine the change in strain or stress caused by drilling of holes in materials or samples in which residual stresses.

When we know the size of the holes, the direction and the sizes released strain and properties of material, we can determine residual stress due to experimental or analytical analysis. This method can only be considered as a semi-destructive method because the drilled hole can be negligible and can be repaired either do welding or inserting a screw or pin. It is often possible that such a repair will alter the stress distribution, and therefore are used instead of through holes - blind holes [4]. In Figure 2 is an example of drilling method with the SINT-MTS 3000 Ring-Core.

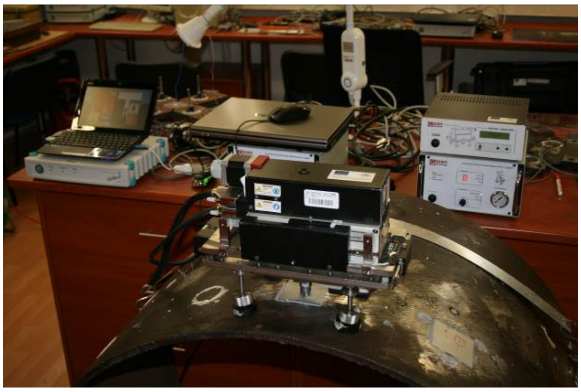

Figure 2. Example of drilling method with the SINT-MTS 3000 Ring-Core

When analysing the blind hole, it is important to know the behaviour of the local area of the thin plate. In ASTM E 837-13, it is recommended to create holes after small increments of depth [5]. This is done to obtain data for judging whether the residual stress across the depth is uniform. If the residual stress with the depth of measurement changes, the calculated stress is always less than the actual maximum. Schematic representation of residual stresses measurement is shown in Figure 3 [4].

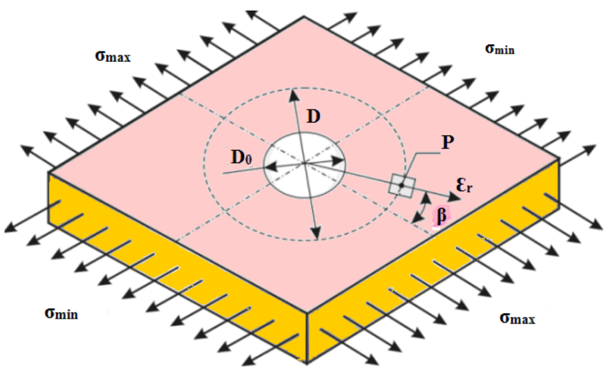

Figure 3. Schematic representation of residual stresses measurement

Released surface radial strains correspond to the stresses according to relation

$$\varepsilon_r = (\overline{A} + \overline{B}\cos 2\beta)\sigma_{\max} + (\overline{A} - \overline{B}\cos 2\beta)\sigma_{\min}, \quad (1)$$

where: ε_r represents a released stress in the radial direction by a strain gauge centred at point P,

$\overline{A}, \overline{B}$ are calibration constants,

β is the angle measured in the clockwise direction from the strain gauge direction $\sigma_{\max}$,

$\sigma_{\max}$ is the maximum main stress at the place of the hole before drilling,

$\sigma_{\min}$ is the minimum main stress at the place of the hole before drilling,

D is the mean diameter of the strain-gage rosette,

D_0 is the diameter of the drilled hole.

The following relations are used for quantification of constants $\overline{A}$ and $\overline{B}$ for materials with given elastic properties

$$\overline{A} = \frac{-\overline{a}(1+\mu)}{2E}, \quad (2)$$

$$\overline{B} = \frac{-\overline{b}}{2E}, \quad (3)$$

where: E is Young's modulus,

μ is Poisson number,

$\overline{a}$, $\overline{b}$ are dimensionless, almost material-independent constants.

The non-dimensionless constants $\overline{a}$ and $\overline{b}$ vary with the depth of the hole. Both can be considered independent of material properties. They are independent of Young's modulus and they are change less than 1% for the Poisson ratio from an interval of 0.28 to 0.33 [4].

The RS-200, SINT-MTS 3000 and SINT-MTS 3000-Ring-Core drilling machines are used for the determination of residual stress at the Department of Applied Mechanics and Mechanical Engineering of the Technical University in Košice. Since the authors devoted themselves analysis to stress around of groove using the PhotoStress method, in the next part will be closer described the device for drilling the groove.

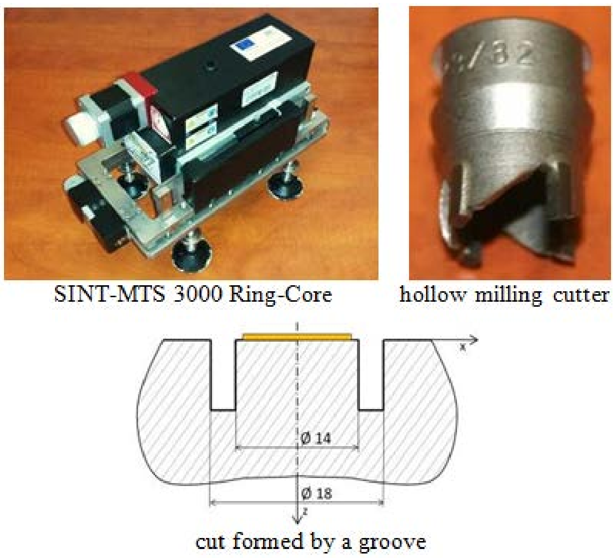

Figure 1. SINT-MTS 3000 Ring-Core

The measuring device SINT-MTS 3000 Ring-Core is used to determine residual stresses using the Ring-Core method, which is used to evaluate homogeneous and non-homogeneous stresses by the depth of the drilling material.

The principle of the method is derived from the drilling method, with residual stresses in the material being released when milling the annular groove around the strain gauge of rosette. The drilled slot has the dimensions D = 18 mm (outer groove diameter), d = 14 mm (internal groove diameter), h = 4-5 mm (groove depth) [4].

In Figure 4 is a drilling machine SINT-MTS 3000 Ring-Core, a hollow milling cutter to make a groove and principle of Ring-Core.

The SINT-MTS 3000 Ring-Core system is a fully automated device to determine residual stresses by the drilling method of groove.

3. Determination of Residual Stresses around the Groove Using the Photostress Method

Reflexive photoelasticimetry belongs to among optical experimental methods used to determine strain and stress on the surface of the objects under investigation. The measuring instruments of the method are called polariscopes (Figure 5).

Figure 5. Reflection Polariscope LF/Z-2

By photoelasticimetry methods are detect, for example, residual stresses in models and real components [6,7,8]. Tasks can be solved at static and dynamic loads [9].

Despite advances in numerical methods, it is not possible to analyse residual stresses unequivocally using numerical methods. For that consequently, experimental methods in the area of detection and measurement of residual and operating stress are now irreplaceable. When working stress on components of machine or structural systems by drilling methods and in detecting stress and strain sizes, you need to know the correctness of the workflow. The aim of the work was to assess the suitability of drilling the hole in photoelastic material for subsequent quantification of residual stresses in the future.

In the case of direct application of the photoelastic of material used in the reflection photoelasticity to the components, the PS-1D material was affixed to a part of the pipeline of one-meter diameter. By strain gauging it was found that residual stress levels were increased in the pipeline. Our task was to test the functionality of the photoelastic material after application on the curved surface with subsequent drilling with the SINT-MTS 3000 Ring-Core.

The two-component PC-1 glue was used to adhere to the four photoelastic materials measuring 7x7 cm. It contains PC-1 resin and PCH-1 hardener. The glue manufacturer gives the formula to calculate the proportion of resin and hardener. In our case, the resulting values were as follows:

PC-1 resin: $30.100/110 = 27,27g$,

PCH-1 hardener: $30.10/110 = 2,72g$.

After approximately 4 minutes of mixing of the components, the adhesive was applied to the samples and after careful cleaning and degreasing of the place of affixed on the surface of the pipeline (Figure 6).

Figure 6. Application of two-component adhesive and photoelastic material on a pipeline

After the adhesive had dried, the drilling device SINT-MTS 3000 Ring-Core was glued with two-component of adhesive X60 above the examined photoelastic material. After connecting the whole apparatus, it was drilled groove into the photoelastic material PS-1D (Figure 7).

Figure 7. Drilling with SINT-MTS 3000 Ring-Core

Figure 8. Setting the MTS 3000 Ring-Core drilling parameters

Figure 9. Milling into photoelastic material PS-1D

Appropriate drilling software has continuously corrected machine speed, drilling speed and depth. After an initial of contact by hollow milling cutter with the photoelastic material, milling was continued through an optically sensitive material (0.432 mm thickness) followed per layer of adhesive (0.312 mm thickness). The software automatically evaluated the depth of drilling (Figure 8) to after the metal cutter touch (Figure 9). The manufacturer recommends deepen of hole more about 0.04 mm.

Figure 10. Analysis of the drilling results through polariscop LF/Z-2

Figure 11. Detailed view of isochromatic pattern around the groove

It followed the removal of the drilling device and the connection of the LF/Z-2 reflective polariscop to detect loosened strains, respectively suitability of the chosen process without emergence residual stresses (Figure 10). It was drilled only through photoelastic material.

From detailed view in Figure 11 it can be stated that during drilling in place No. I are visible colour entities affected by the milling cutter. In location No. II was not identified by isochromatic patterns, which is confirmed by the fact, that the residual stresses were not introduced into the optically sensitive material by drilling.

4. Conclusion

A number of experimental measurements still need to be carried out to verify and continue the newly proposed methodology for quantizing residual stresses by the Photo Stress method on real machine and machine elements. The author's workplace has a modern hydraulic loading device for uniaxial and planar stresses with a maximum load force in both directions of 100 kN. At present, work is being done to carry out experimental measurements to determine the stresses on annealed samples (without residual stresses) at a precisely defined load.

Acknowledgements

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