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EVALUATION OF RESIDUAL STRESSES USING OPTICAL METHODS

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Abstract: The paper deal with quantification of residual stresses by the drilling method and design of the methodology of using optical device LF/Z-2 for their verification. The optical methods have been used for strain analysis for years, but with the continuous development of new and more accurate measuring instruments and devices, are solved the possibilities of creating new application methodologies. For using the Optical PhotoStress method for quantifying residual stresses, has been designed an accurate positioning device to analyse the released deformations around the drilled hole in multiple steps as considering by ASTM E837-13a for drilling methods.

1 Introduction

Determination of causes and the prediction of the failure of the bearing members of structures is still a highly topical issue related to the assessment of the lifetime of structures, machines, equipment, etc. It should be pointed out that many failures of parts of structures, systems or machines are not only due to the stress induced by the load, but are also due to the occurrence of residual stresses. These also occur in unloaded structures or machine parts. They can be caused not only by the operating load, but also by the production technology (casting, rolling, pressing, etc.) as well as by welding. Determining the occurrence of residual stresses, their size and direction is problematic without carrying out experimental measurements. 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, it is necessary to know and quantify these stresses to predict the occurrence of disorders. Currently, the drilling method is most commonly used to determine residual stresses in the material. This is a semi-destructive experimental method of quantifying residual stresses in a selected point. The authors use the SINT MTS 3000 drilling equipment or the RS 200 drilling machine to solve specific practical tasks.

2 Analysis of the causes of defects in constructions with a combination of hole drilling methods and photoelasticimetry

Despite the advances made in numerical methods, it is still not possible to unambiguously analyse the residual stresses using numerical methods. Therefore, even nowadays experimental methods in the area of detection and measurement of residual stresses have their irreplaceable place. It is necessary to know the individual stages of the experiment when stressing machine components or assemblies with drilling and optical methods and then determining stress and deformation sizes. The aim of this experimental part was to propose a methodology for determining residual stresses using optical methods, namely the PhotoStress method together with hole drilling method [1-12].

American norm ASTM E837-13a is currently the only generally accepted standard that deals with investigating residual stresses by experimental mechanics. However, there are a number of limitations in this standard. For direct drilling into the component and subsequent examination of the deformation values by optical methods, it was necessary to design and manufacture the device (Fig. 1 a, b), which would connect the two mentioned methods of detecting stresses and deformations in structural members. The idea was to design a device with an adjustable drilling head and an optical device for detecting deformation fields - the LF/Z-2 polariscope. The principle was to accurately drill into a defined depth of the component with a special cutting tool. Subsequently, by means of a stepper motor, is released by the horizontal displacement of the drilling head outside the opening the space for measuring the residual stresses by the LF/Z-2 polariscop with a compensator [8,13-15].

At the Fig. 1a is a view on one of the designs of a 3D model of a positioning drilling device, and at the Fig. 1b is the resulting real constructed device. The motors are used for horizontal and vertical movement of the drilling head and for rotating the drill or milling cutter.

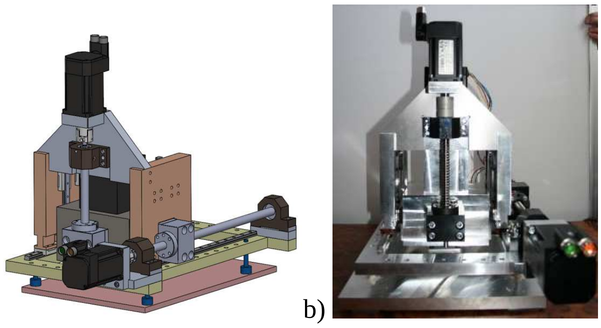
a) b)

Figure 1 Proposal of the drilling device (a) and really configurable positioning drilling device (b)

The precise positioning drilling device was largely constructed from aluminum alloy due to its satisfactory strength and total weight of the device. Subsequently was tested the accuracy of the drilling device for horizontal and vertical movement of the drilling head and drilling through the unloaded samples with already applied photoelastic coating. Also tested was a hydraulic load device located in the newly built Prototyping and Innovation Center of the Faculty of Mechanical Engineering TUKE, which is capable of generating loads of up to 100 kN in two direction. The annealed samples were drilled under load and through the polarizing device and the photoelastic coating were examined the formed entities [16].

In the following section of experimental testing and investigation of stress fields, was designed an aluminum sample of dimensions and shape as shown in Fig. 2. The shape of the samples, resp. its 65 mm edges, were adapted for further testing by other methods for detecting stresses and deformation fields in the component.

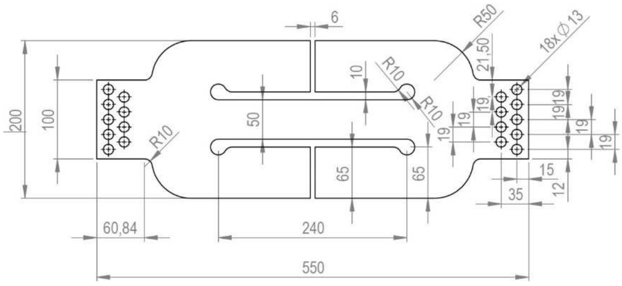

Figure 2 Shape and dimensions of samples used for drilling detection and optical method PhotoStress

The sample was annealed to eliminate residual stresses. A photoelastic coating PS-1D was consist of a two-component adhesive (resin + hardener) was applied to the sample from aluminum as indicated by the manufacturer [15,16].

Furthermore, the simulated stresses were determined on a uniaxial loaded aluminum sample. It consisted in the gradual drilling of the blind hole and the subsequent observation of the emerging photoelastic entities in its vicinity. A strain gauge cross was applied to the test sample to check the stability of the induced load (Fig. 3). Each grid was connected to the quarter bridge. Time warp was recorded and evaluated by Catman Easy.

Figure 3 Aluminum sample with applied strain gauge cross

At the Fig. 4 is a view on a drilling process on an aluminum sample loaded with a hydraulic loading apparatus and stress measuring by optical apparatus LF/Z-2.

Figure 4 Drilling with positioning device and measuring of stresses with the optical device LF/Z-2

The mill cutter speed with diameter 3.2 mm (or 18 mm) was 120 rpm. The released relative deformations around the blind hole were analyzed in twenty steps with an increment of 0.1 mm. During the whole measurement, the tensile force was 7.5 kN. By moving the drilling head in the horizontal direction to a position allowing the use of the polarisop, directions and differences of the main proportional deformations were observed. After each step were created images of isoclinic and isochromatic lines (Fig. 5).

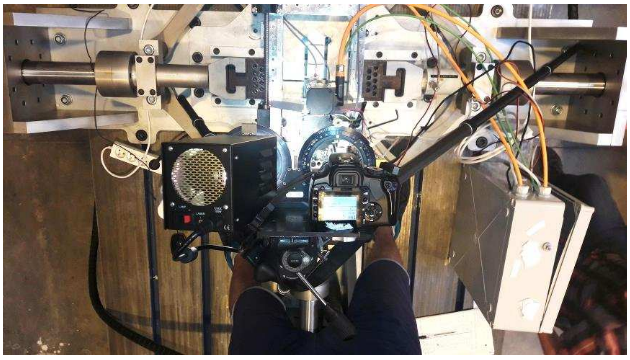

Figure 5 Process of registration of isoclinic and isochromatic lines with a polariscop LF/Z-2

The entire measurement phase without the application of strain gauge and photoelastic coating took approximately 2 hours. At the Fig. 6 is a more detailed time record of the vertical displacement of the drilling head into the annealed sample registered by the displacement sensor.

In the next section, isochromatic lines for a given depth of 0.5 mm (Fig. 7), 1.0 mm (Fig. 8), 1.5 mm (Fig. 9) and 2 mm (Fig. 10) are given for comparison of the released strain ratios. Blind hole drilling was not realized for larger depths (in according of ASTM E 837-13a). From Fig. 7 - Fig. 10 it stands to reason that more pronounced bands (isochromatic lines) are more visible when drilling an annular groove, which corresponds to the results of numerical modeling. Despite this, it can be stated that these are relatively low stresses levels, their quantification is more demanding and the measurement inaccuracy is also higher in this case. On the other hand, low levels of simulated "residual" stresses do not pose a risk to the safe operation of machinery and equipment. Higher sensitivity of the simulated stress measurement is possible by using an optically sensitive coating with a greater thickness, which however limits the use of cutting tools (milling cutter or hollow cutter).

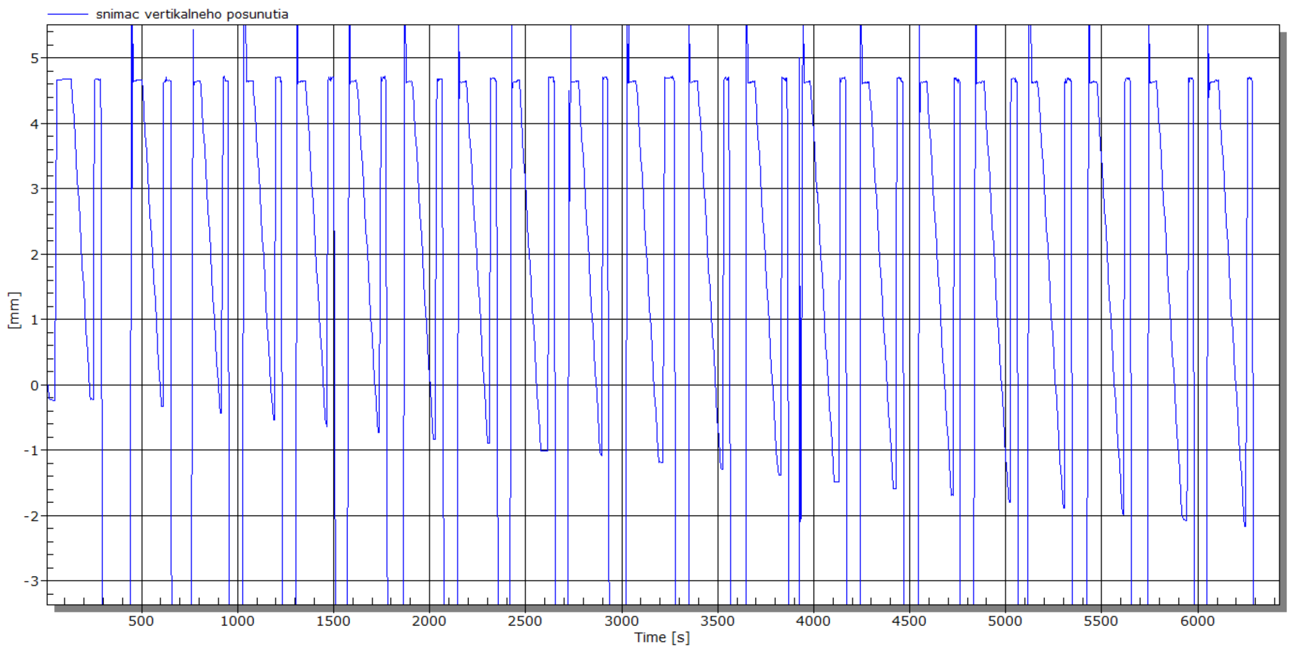

Figure 6 Time recording from vertical movement of hole drilling

Within the proposed methodology of quantification of residual stresses using the PhotoStress method, it was due to the comparison of achieved results with the method of drilling, resp. Ring-Core method considered using identical cutting tools 3.2 mm diameter cutter used with RS-200 and hollow cutter used with SINT-MTS 3000 Ring-Core. The limiting factor is the shape of the cutting tools for drilling the blind hole, respectively. an annular groove, since the thickness of the adhesive and the coating used had to be added to the depth itself. Therefore was used the thinnest coating of PS-1D with a thickness of 0.5 mm.

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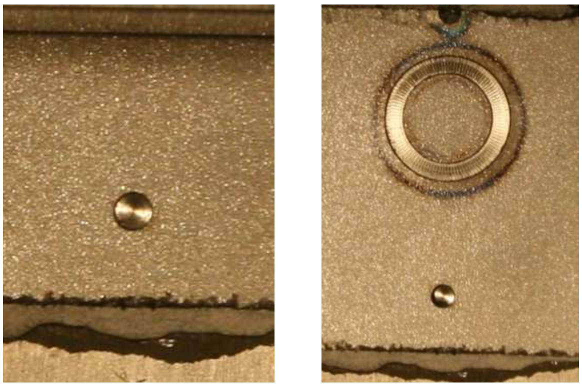
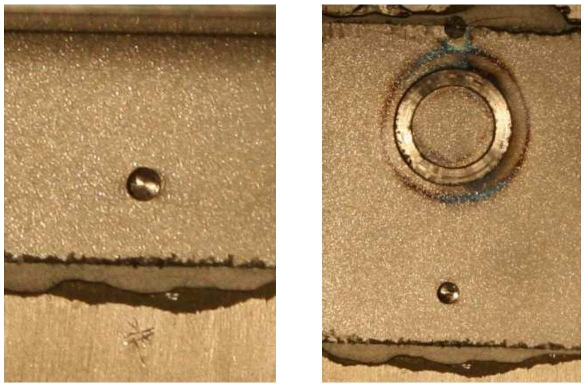


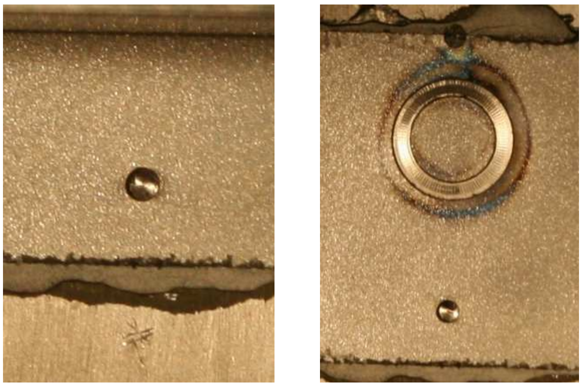
a) b)

Figure 7 Isochromatic lines for 0.5 mm depth a) blind hole, b) annular groove



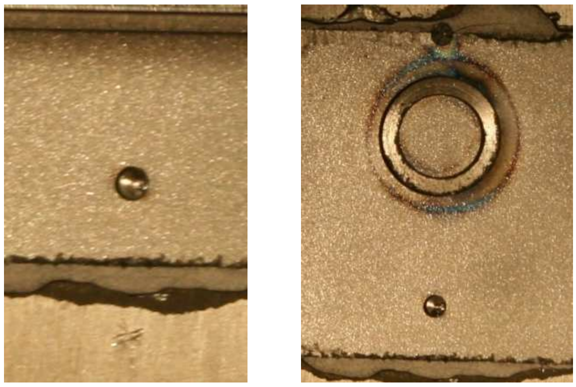
a) b)

Figure 9 Isochromatic lines for 1.5 mm depth a) blind hole, b) annular groove



a) b)

Figure 8 Isochromatic lines for 1.0 mm depth a) blind hole, b) annular groove



a) b)

Figure 10 Isochromatic lines for 2.0 mm depth a) blind hole, b) annular groove

The time recording of the relative deformations in the test sample during the experimental measurements is shown in Fig. 11. It is clear from the figure that there were no significant variations during the measurement, the correct operation has been confirmed of the simulated load-causing hydraulic load device. The hydraulic loading device can be considered as one of the key elements of the measurement chain, since if the stress in the sample analysed is changed in the experiment, the obtained results could not be considered as relevant.

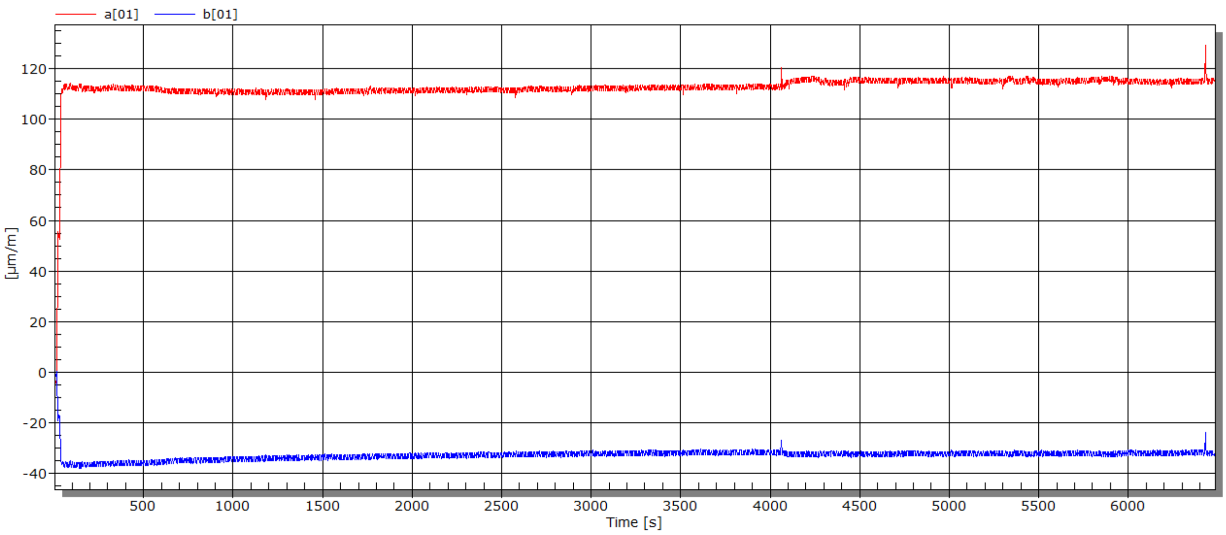


Figure 11 Time recording of relative deformations on loaded test sample

Conclusion

In the submitted paper, the methodology of quantification of residual stresses was proposed and verified. On the basis of the results obtained, it can be stated that an accurate positioning device has been designed to evaluate the released relative deformations during the progressive drilling of the blind hole, respectively an annular groove using the PhotoStress optical method. These devices were used in experimental measurements on unloaded samples as well as annealed samples loaded with simulated loads. On the basis of the analysis of isochromatic bands around a 3.2 mm diameter blind hole and around a groove with an outer diameter of 18 mm and an internal diameter of 14 mm registered with a reflection polariscope, it can be concluded that the more visible deformations are around the annular groove. For experimental measurement, the PS-1D coating was chosen to achieve the lower adhesive and coating thickness. The disadvantage of said coating is less sensitivity to the deformation released. It is true that the thicker the coating, the more accurate the measurement. This fact will be dealt with in the next period, as the cutting tools used by RS-200 or SINT-MTS 3000 Ring-Core devices were used in the present work.

The advantage of applying the optical method for quantifying residual stresses is, among other things, the possibility of full-field deformation analysis in the investigated area on a real structure or device. Despite the good consensus of the results obtained by experimental measurement and numerical computation, which is part of the work [17-21], the results achieved cannot be considered final.

There is wide scope for:

- research into the possibility of using the proposed methodology for inhomogeneous, anisotropic, composite materials,
- optimizing the design of the pointing device not only to reduce its weight but also to position it in the third axis, allowing the device to be used for the drilling method, respectively Ring-Core,
- use of the proposed equipment not only for the PhotoStress method, but also in combination with the DIC (Digital Image Correlation) method, with which we also have extensive experience in the area of deformation and stress analysis in the vicinity of concentrators at the KAMASI workplace,
- automating the drilling and strip reading process by compensator, not only significantly reducing the length of the experimental measurement, but also eliminating the adverse effect of the human factor e.g. when positioning the device, etc,
- testing new cutting tools.

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