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COMPARISON OF RESULTS RECEIVED BY HOLE DRILING METHODS FOR DETERMINATION OF RESIDUAL STRESSES

POROVNANIE VÝSLEDKOV ZÍSKANÝCH ODVŔTAVACÍMI METÓDAMI PRI ZISŤOVANÍ ZVYŠKOVÝCH NAPÄTÍ

Abstract

Residual stresses acting in structural elements and nods deserve a great attention. They are often the source of many accidents. There are a lot of various procedures and methods for their determination. Residual stresses cannot be measured using conventional procedures, since the strain sensor (resistance strain gage, photoelastic coating) is insensitive to the loading history of the examined part and only measures the strain changes occurred after its installation. From the quantification point of view, a hole drilling method appears to be the simplest. However, this method only makes it possible to determine residual stress in the examined point. Its advantage consists in quick application and prompt evaluation of stresses.

Abstrakt

Zvyškové napätia, pôsobiace v prvkoch a uzloch konštrukcií si zaslúžia veľkú pozornosť. Sú často zdrojom vzniku mnohých havárií. K ich určeniu existuje rad rôznych postupov a metodík. Meranie zvyškových napätí nie je možné vykonať konvenčnými postupmi, pretože snímač deformácie (odporový tenzometer, fotoelastická vrstva) je necitlivý k histórii zaťažovania vyšetrovanej časti a meria len zmenu deformácie po inštalácii snímača. Z hľadiska kvantifikácie najjednoduchšou sa javí semideštruktívna odvŕtavacia metóda. Avšak uvedená metóda umožňuje určiť zvyškové napätie len v skúmanom bode. Jej výhoda spočíva v rýchlej aplikácii a pohotovom vyhodnotení napätí.

1 INTRODUCTION

To utilize the strength properties of material as much as possible, this requires taking into account the presence of residual stresses, too. Their convenient effect can improve the ratio of the strength of a part to its weight and at the same time decrease its price. A suitable distribution of internal stress can not only result in an increased safety degree, but in many cases an increased productivity, as well. In investigating residual stresses, a lot of complications occur, and insufficient theoretical knowledge of this issue usually results in reluctance to apply new pieces of knowledge in practice [1].

In this paper, residual stresses were measured using two hole drilling methods – a strain gage method and a photoelastic coating method. The aim of application of these methods is to verify the proposed photoelasticimetric method, which has not been utilized for the determination of residual stresses to a greater extent at our workplace so far.

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2 SPECIMEN PROPERTIES AND EXPERIMENT

The experiments were made on steel specimens with the chemical composition of the declared grade *S 355*, supplied according to *EN 10025*, with the steel designation according to *EN 10 027.1,2* (*Rm = 550 MPa*). Specimens for experiments were cut out of hot rolled sheets (Fig. 1). Within research tasks, residual stress measurements were made according to the ASTM Standard Test Method E 837-01 (Fig. 2). The experimental results showed that residual stresses were present in the points from which the specimens were taken. The measurements on the top side of the sheet confirmed that the nature of residual stresses did not change, but their size changes from point to point. The measurements on the back side of the sheet specimen confirmed the full coincidence of the course of residual stresses at the edge and the centre.

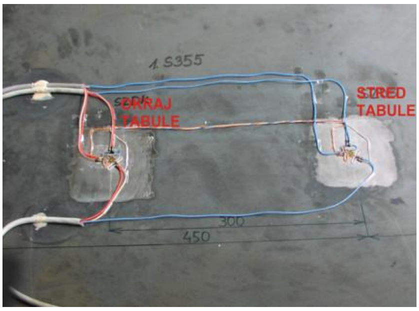


Fig. 1 Steel sheet with strain gage rosettes

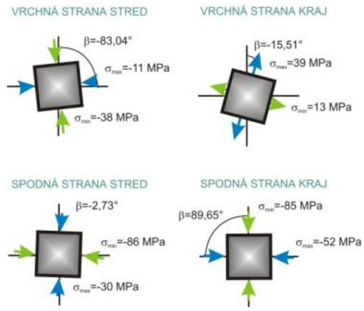


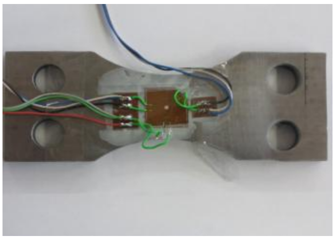
Fig. 2 Magnitudes and directions of measured residual stress (ASTM)

Test specimens were made of the sheet of defined material (using the laser method), whose shape and size were prescribed for flat bending fatigue tests (according to STN 42 0363). After cutting out the specimens, we assumed that, as a result of release of residual stresses, the directions and magnitudes of residual stresses changed. Through secondary machining operations to eliminate the heat-affected zones and to treat the surface quality by grinding, tensile stresses were probably introduced into the surface layer. The assumed redistribution of residual stresses in the treated test specimens was confirmed by a change in the surface hardness.

In order to assess the fatigue strength of the tested material in a comprehensive way, it was necessary to quantify the presence of residual stresses. To measure them, we used hole drilling methods, where strain changes after removal of material were evaluated using photoelastic coatings and strain gages. The choosing of the residual stress measuring point was accommodated to methodical conditions, while the edge of the tested specimen was the most convenient, because of stress concentration. However, during drilling in the edge points there was the risk that the applied photoelastic coating may separate, and the possible separation of the applied coating may cause significant misrepresentation of the measured values. For this reason, the specimen centres were chosen as measuring points.

We used a photoelastic coating of Photolastic PS-1B type with the thickness of 3.175 *mm*. The chosen shape of the coating was the same as the shape of the test specimen. In order to eliminate the introduction of undesirable stresses into the coating during its treatment, we used the water jet technology. The treated photoelastic coating was applied to the test specimen using two-component epoxy adhesive with a reflex effect, and with the thickness of ca 0.3 mm.

For strain gage measurements, we used a strain gage rosette of 3/120RY 21 type (k-factor 2.07± 1%) by Hottinger Baldwin Messtechnik company (HBM). The rosette was applied onto the thoroughly treated surface (see Fig. 3) using the procedure and means recommended by the manufacturer. Because of the structure of the stand of the measuring device, we had to avoid possible movements occurring during drilling, so that the secondary effects of clamping cannot cause changes in measured stresses. For this purpose, we made a hole in the sheet, whose dimensions were the same as the dimensions of the tested specimens (see Fig. 4).



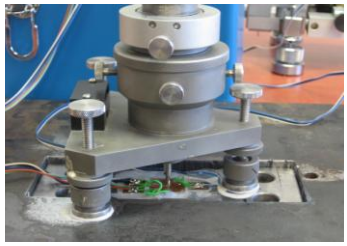
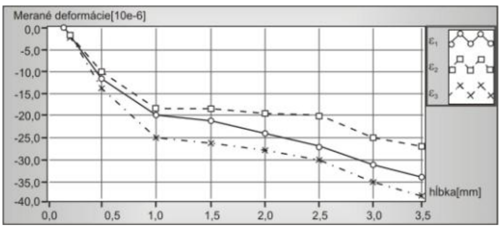


Fig. 3 Strain gage rosette 3/120RY 21 **Fig. 4** Positioning of specimen into frame

In selecting the drilling machine, we took into account the necessity of controlling the drilling revolutions, in order to eliminate the heat effect on the photoelastic coating, as well as a possibility of using a greater drill diameter, for higher resolution of the formed bands. Therefore the drilling machine of RS – 200 type was used in the experiment.

3 CALCULATION RESULTS

In processing the data measured using the strain gage method for the blind hole, we followed ASTM E 837-01 Standard [3, 4]. The used specimen (Fig. 3) with the thickness h = 12 mm is considered as thick according to the Standard (min. 1.2D, where D is the central diameter of the rosette). For this specimen, we obtained 8 sets of data about strains ε_1, ε_2, ε_3 with an increasing depth, while the first data set was intended for the depth of 0.2 mm (hereinafter 0.05D). However, the Standard prescribes the drilling by 0.05D increments down to the final depth of 0.4D [2]. Therefore we had to use the additional interpolation for the determination of calibration constants. Fig. 5a shows the actually measured values of released strains, and Fig. 5b shows the interpolated values, during drilling on the back side of the tested specimen.



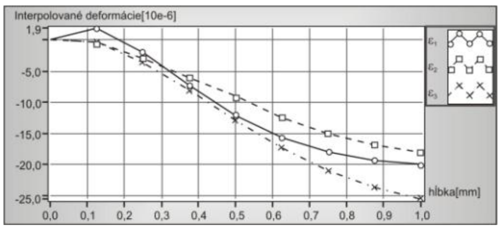
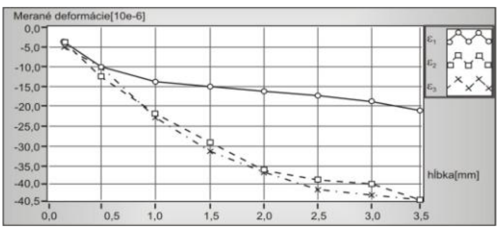


Fig. 5a Measured strains on back side **Fig. 5b** Interpolated strains on back side

The same procedure was applied to the top side of the tested specimen, whose results of the measured and interpolated strains are shown in Fig. 6.



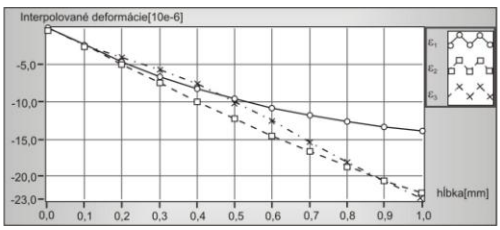


Fig. 6a Measured strains on top side **Fig. 6b** Interpolated strains on top side

The sizes and directions of normal stresses $\sigma_{max,min}$ evaluated using the averaging method according to ASTM represented the reference values for eight measurement sets along the whole depth. On the other hand, strain changes occurring during drilling the hole in the specimen (Fig. 7), determined using the photoelastic coating method, only represented the values on the material surface. Therefore we chose the residual stresses close under the surface (h = 0.1 mm) as the reference values of the strain gage method.

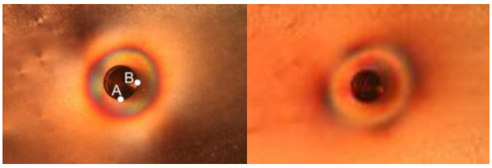


Fig. 7a Coloured strips near by hole on top of the side

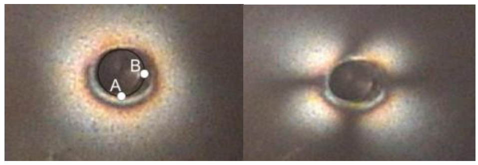


Fig. 7b Coloured strips near by hole on back of the side

The sizes of the quantified residual stresses determined from the photoelastic coating, calculated using the applicable separation method, together with the stresses from the strain gage measurement at the depth of 0.1 mm, are shown in Tab. 1.

Tab. 1 Magnitudes and directions of principal residual stress.

Specimen side	Strain gage meth. $\sigma_{1,2}$ [MPa]		Photoelastic coating $\sigma_{1,2}$ [MPa]		Difference [%]
obverse	+43	+38	+45	+40	max.5
reverse	+5	+4	-	-	-

4 SUMMARY AND COMPARISON

The aim of the paper was to verify the suitability of the proposed residual stress quantification methodology, through the photoelastic coating method, using the strain gage method. The both presented methods determine changes in the stress state formed during drilling a hole in a specimen where residual stresses occur. Tab. 1 presents the results, while the relative deviation of the values measured on the top side of the tested specimen is below 5%. On the back side of the specimen, indistinct bands appeared after drilling, which complicated the exact determination of released stresses. By comparing with the strain gage method, on this side of the specimen only the quantitative consistence can be stated. Despite of this we can consider the results of the proposed methodology of quantification of residual stresses using the photoelastic coating as satisfactory.

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