APPLICATION OF PHOTOSTRESS METHOD IN STRESS ANALYSIS OF A ROTATING DISC

The presented article demonstrates the application of PhotoStress® method in stress analysis of a rotating disc of a constant thickness, which was made of a photoelastic material PS-1A. Isoclinic fringes were observed on the rotating disc using linear polarized light at revolutions 5 000 RPM. Observations were carried out under angle parameter 0 º to 90 º with 10 º increase. A set of isostatic lines of I and II set was made from the set of obtained isoclinic lines. During gradual increase of rotations of the rotating disc up to 17 000 RPM, and with circular polarized light, we observed the distribution of colourful isochromatic fringes on the rotating disc. The field of isochromatic fringes, gained experimentally, at 15 000 RPM was compared with the field which was gained by means of a numerical analysis.

Key words: photoelastic material PS-1A, PhotoStress® method, isochromatic fringes, isoclinic lines, rotating disc

INTRODUCTION

The PhotoStress® method is an experimental method of mechanics, which is used in static as well as dynamic stress analyses [1]. Photoelastic coating is used in which, when loaded and illuminated by polarized light from a reflection polariscope, the birefringence phenomenon occurs with characteristic colourful isochromatic fringes. As far as static stress analyses are concerned, the classic source of white light is used. As regards dynamic stress analysis, the stroboscopic light is applied. In addition to visualisation of stress displacements, the method allows us to quantify the stresses in every point of the analysed surface. Fundamental principles and procedures of measurements and determination of directions as well as magnitudes of individual principal normal stresses in every point of the analysed surface by means of PhotoStress® method are stated in publications listed [2-5]. The aim of the presented article is to point out possible applications of PhotoStress® method within dynamic stress analyses. The above-mentioned is presented on a rotating disc of a constant thickness, made of photoelastic material PS-1A.

EXPERIMENTAL PART AND RESULTS

Using water jet, the rotating disc of constant thickness 3,125 mm was cut from plane, optically sensitive plate, from photoelastic material PS-1A, in dimensions according to Figure 1.

Photoelastic coating PS-1A exhibits perfect sensitivity that enables its use in stress analysis in the elastic as well as in the elastic-plastic area. It is distributed with a

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reflection layer in the back side. Optical and physical features of the photoelastic coating PS-1A are listed in Table 1 [4].

Table 1 **Optical and physical features of photoelastic coating PS-1A**

Strain-optical coefficient K / -	0,150
Elongation / %	5
Elastic modulus E_c . 10^5 / MPa	0,025
Poisson's ratio µ / -	0,38

The experimentally analysed rotating disc was subjected to loads by centrifugal forces which were induced by rotation of the disc via electric motor HSM 60. Figure 2 depicts the measurement and loading apparatus for visualisation and quantification of parameters belonging to individual photoelastic entities which occur during the rotation of the disc under analysis. Reflection polariscope LF/Z-2 with stroboscopic source of white light was used for visualisation of stress fields distributions during disc rotation. Digital laser tachometer Mi-
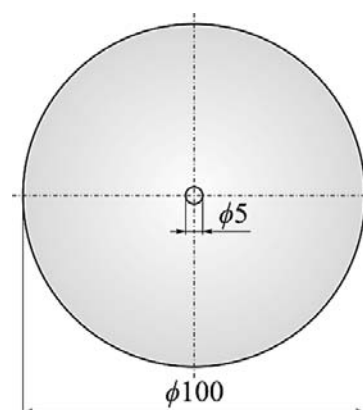

Figure 1 Dimensions of the rotating disc

Figure 2 Measurement and loading apparatus for the rotating disc

Figure 3 Isoclinic fringes

Figure 4 The set of isoclinic fringes

— Isostatic lines of I. set
······ Isostatic lines of II. set

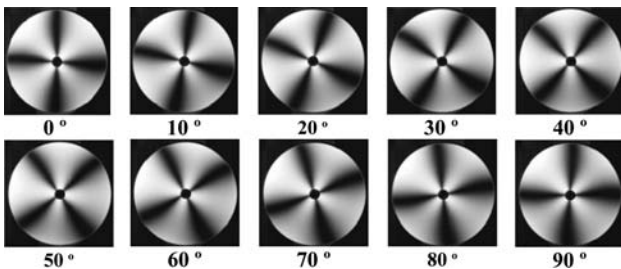**Figure 5** The set of isostatic lines of I and II set

Figure 6 Disc without loads

croprocessor Laser Tacho Pro was used for the measurement of revolutions.

On the rotating disc, illuminated by plane polarized light from the reflection polariscope LF/Z-2, we could observe isoclinic fringes at 5 000 RPM. The isoclinic fringes appeared as radial straight lines characterised by the angle parameter of the analyzer or angle parameter of the isoclinic α. Figure 3 depicts isoclinic fringes of the rotating disc with angle parameter 0 ° to 90 ° with 10 ° increments. Considering Figure 3, it is obvious that isoclinic fringes with angle parameter 0 ° and 90 ° are equal.

From individual images of isoclinic fringes we were able to draw the set of isoclinic lines (Figure 4) from which subsequently, the set of isostatic lines of I and II set, or the set of stress trajectories (Figure 5) was created.

Considering Figure 5, it is obvious that isoclinic fringes of all angle parameters run through one point placed in the rotation centre. This is the so called singular point. Since the isoclinic fringes move during clockwise rotation of the analyzer in the same direction of rotation, the singular point is considered positive singular point of the second order. Figure 5 depicts the isostatics of the first order as radial straight lines which run through the axis of the rotating disc. The figure also depicts the isostatics of the second order as concentrated circles with the centre in the rotation axis. Both sets of isostatics intersect in the right angle, what matches the theory.

On the rotating disc of a constant thickness we evaluated the distribution of stresses during its rotation. Figure 6 depicts the disc of a constant thickness without loads applied.
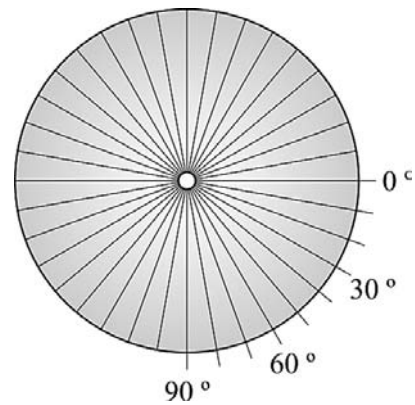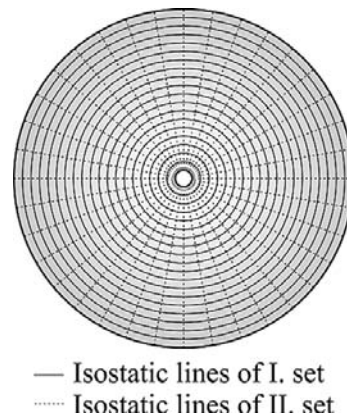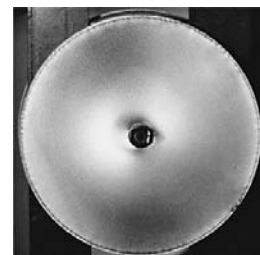
The isochromatic fringes compared at circular polarized light for 10 000 RPM up to 17 000 RPM are shown in Figure 7.

Considering Figure 7, it is obvious that the isochromatic fringes during disc rotation create centred circles. Figure 8 depicts the detail of isochromatic fringes on the disc rotating at 15 000 RPM in the area of inner diameter.

For the comparison of experimental measurement a numerical analysis of the rotating disc was carried out in the programme ANSYS 14.1 at 15 000 RPM. Figure 9 depicts the web model of the rotating disc with constant thickness. Figure 10 defines the edge conditions while the fixed support (A) and rotational velocity 15 000 RPM (B) are defined on the inner diameter.

Figure 11 depicts the distribution of isochromatic fringes which were identified by means of a numerical analysis at 15 000 RPM. The field principal stress difference is depicted in Figure 12.
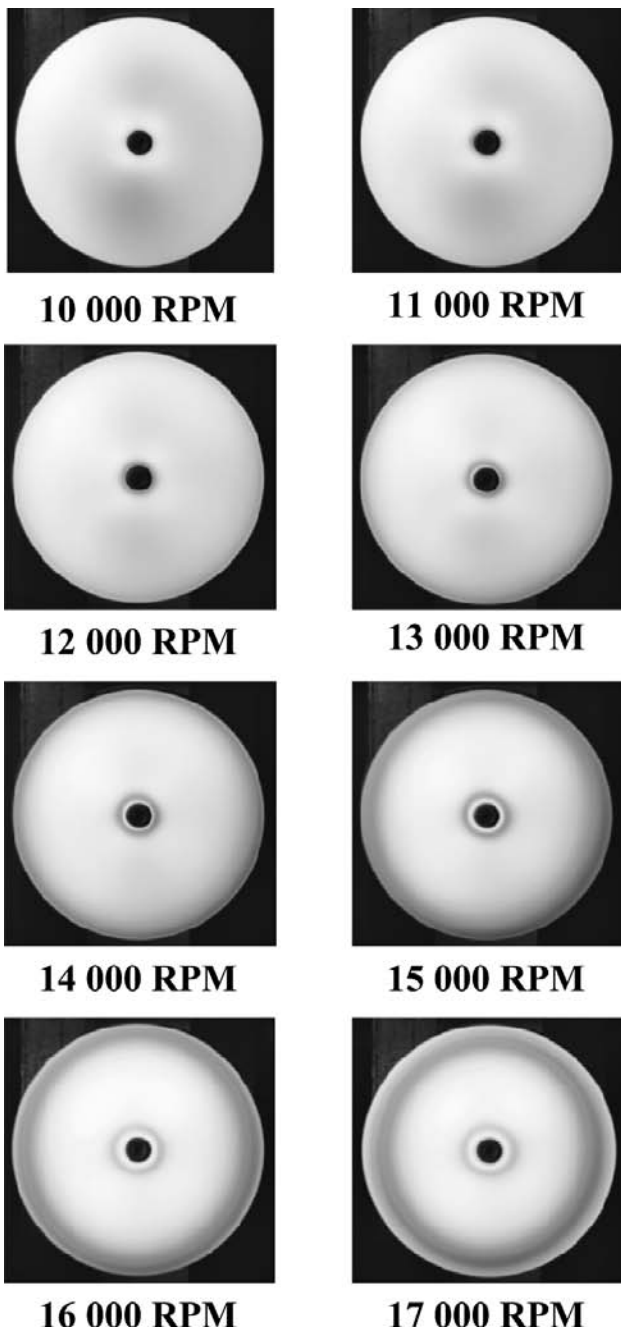
10 000 RPM   **11 000 RPM**

12 000 RPM   **13 000 RPM**

14 000 RPM   **15 000 RPM**

16 000 RPM   **17 000 RPM**

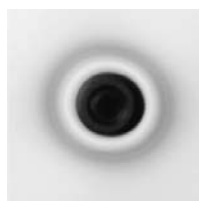**Figure 7** Isochromatic fringes

Figure 8 The detail of isochromatic fringes

DISCUSSION

Isochromatic fringes can be observed in the experimental analysis of a rotating disc of a constant thickness as they occur in the area of inner diameter. In this area, the isochromatic fringes are narrow and densely placed as characterised by a high stress gradient in this area. The highest difference in principal stresses can be found
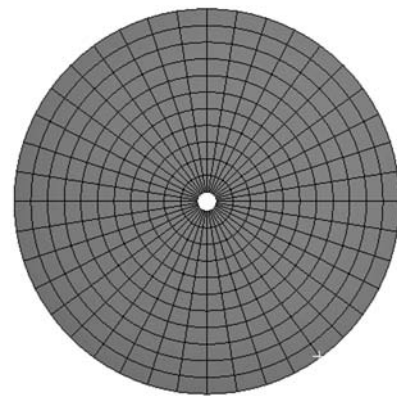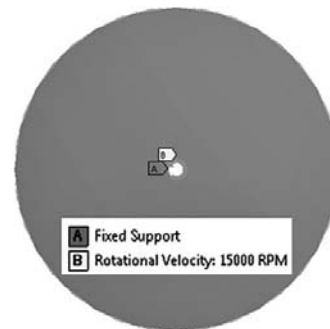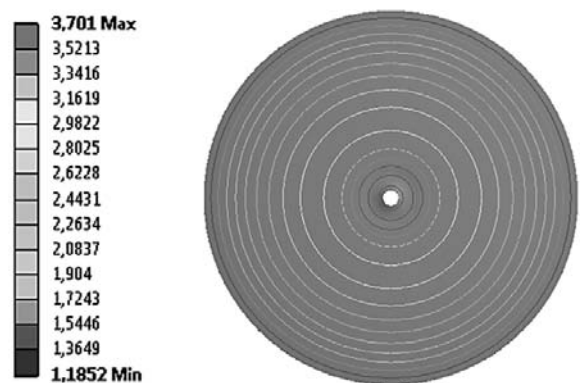

Figure 9 Web model of the disc

A Fixed Support
B Rotational Velocity: 15000 RPM

Figure 10 Defined edge conditions

3,701 Max
3,5213
3,3416
3,1619
2,9822
2,8025
2,6228
2,4431
2,2634
2,0837
1,904
1,7243
1,5446
1,3649
1,1852 Min

Figure 11 The field of isochromatics in MPa

3,701 Max
3,5213
3,3416
3,1619
2,9822
2,8025
2,6228
2,4431
2,2634
2,0837
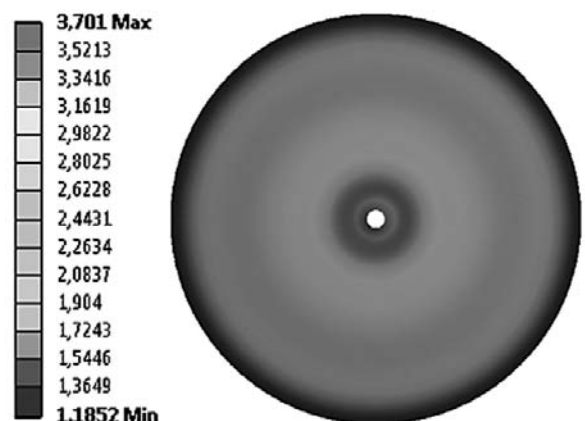1,904
1,7243
1,5446
1,3649
1,1852 Min

Figure 12 The field of principal stress difference in MPa

in the border area of the inner diameter, which is proved by numerical analysis at 15 000 RPM. The highest difference in principal stresses has the value of 3,7 MPa.

CONCLUSION

Considering the analysis of the rotating disc it can be assumed that the PhotoStress® method can be used not only in static analyses using common source of light, but also in dynamic stress analyses using stroboscopic light. The advantage of the method is the possibility of immediate identification of areas with the highest stress concentration. From the distribution of isochromatic fringes we can as well determine if the area of low or high gradient of strains or stresses is in question.

Our future papers will be dedicated to determination of stress state by means of PhotoStress® method considering dynamic periodical and dynamic non-periodical effects [10].

Acknowledgement

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