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New Possibilities of using PhotoStress® Method

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KEY WORDS

PhotoStress® method, software PhotoStress, isochromatic fringes, fringe order, reflection polariscopes

ABSTRACT

The PhotoStress® method allows the determination of strains and stresses in the loaded and photoelastically coated structural members. The quantitative values of differences of the principal strains (stresses) and their directions can be used to obtain the field of strain or stress components on the whole coated surface using further experimental data. In order to accelerate the process of measurement in the point, along the line or on the surface a new software application PhotoStress was designed and developed

by the authors in collaboration with "Kybernetika, s.r.o." company that allows to determine directions and magnitudes of differences of the principal strains or stresses on the basis of a photograph of photoelastically coated objects. The reflection polariscopes M030, M040 and LF/Z-2 with separation methods (the Slitting method, method of oblique incidence, method using a separative tensometer and method of shear stress differences) can be used in the measurement chain. The new program product for these applications, its short description and use are discussed in the present paper.

1. Introduction

The PhotoStress® method is a widely used technique suitable for visual and quantitative determination of directions and magnitudes of the principal strains or stresses on photoelastically coated objects. The authors´ workplace is equipped with three gauging devices for measuring parameters of direction and differences of the principal strains or stresses using the above-mentioned method. M030, M040 and LF/Z-2 polariscopes allow to determine the parameters of direction and differences of the principal stresses, and on the basis of an experimentally determined further parameter each of them allows to separate the principal stresses or principal strains which is a relatively lengthy process especially if applied in several points of a coated surface. In order to significantly accelerate this process a new software application PhotoStress was developed that allows to determine directions and magnitudes of the separated values of the principal strains or stresses in the point, along the line or curve on the basis of a photograph of color isochromatic fringes of loaded objects. At present, the application inlcudes four methods: the Slitting method, method of oblique incidence, method using a separative tensometer and method of shear stress differences, which are used for the determination of the third parameter necessary to assess the separated values of the principal stresses. The basic principle of the PhotoStress method with an example of the determination of the direction and magnitude of the principal normal stresses in the partite ring using the Slitting method of separation is the subject of the paper [1,2,3].

2. Description of PhotoStress software application

PhotoStress software application (Fig. 1) is based on recognition of colors of individual pixels of the color isochromatic fringes created during loading and illuminating the coated objects with polarized light from a reflection polariscope. The order of isochromatic fringes is determined from the color of individual pixels of a photograph which is necessary to identify the values of differences of the principal strains and principal normal stresses. On the basis of bundles of isocline lines the application also allows the determination of direction of the principal strains or stresses in individual pixels of the analyzed surface. In the PhotoStress application the analyzed field of isochromatic fringes is divided into two areas (Fig.2):

■ *area of isochromatic fringe order N in the range from 0 to 0,35,*

■ *area of isochromatic fringe order N in the range from 0,36 to 3,00.*

Fig. 1: *Software application PhotoStress.*

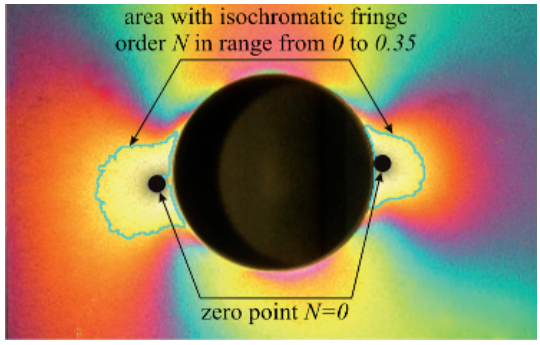


Fig. 2: *Specification of the area of isochromatic fringe orders N in the range from 0 to 0, 35.*

In the areas where the isochromatic fringe orders are smaller than 0,35 the colors are very inconspicuous. To determine the fringe order in this area the null point area is marked as the first (with the fringe order N=O). Consequently, the application bounds the area with the isochromatic fringe order N in the range from 0 to 0,35. In this area, the shortests trajectories between the area of the null point and the isochrom line with the fringe order 0.35 are searched for using the gradient method. Each point in this area is assigned a fringe order on the basis of the ratio of its distance from the null point to the isochrom line of the order 0.35 within the given trajectory. The algorithm for determination of isochromatic fringe order in the area of fringe orders in the range from 0.35 to 3.00 is based on the determination of the color of a given pixel in the HSV color space, where Hue is the prevailing spectral color, Saturation determines to what extent the color is clear and Value represents the rate of distinguishing fair color from grey color, i.e. the index that gives the order of succession of the six photoelastic colors. The RGB value of the color space is assigned to every point of the color fotoelastic pattern. This value represents the relative intensity of red, green, and blue color, which is not sufficient for the PhotoStress® method. This is the reason why the algorithm for transformation of color components from the RGB to HSV color space is integrated into PhotoStress. The H value (Hue) is used in the recomputation of individual color pixels to the value of the fringe order. This value is assigned to the value of the fringe order N according to the defined transformation function. This function is determined according to calibration measurements performed by LF/Z-2 polariscope using Canon PowerShot A480 camera [5, 6, 7, 8].

The 8-direction FloodFill algorithm is used for sequential indexing of the analyzed area.

3. Determination of principal normal stresses by PhotoStress application in the partite ring

To determine directions and magnitudes of the principal normal stresses using the PhotoStress technique the excentrically loaded specimen of the partite ring was used whose shape, dimensions and loading are given in Fig. 3. The 3 mm thick partite ring was covered with PS-1 photoelastic coating 3,125 mm thick. Loading by the force F=1000 N was carried out by loading in the frame as shown in Fig.3.

The measurement and evaluation chain for the determination of magnitudes and directions of the principal strains and stresses by PhotoStress (Fig.4) consists of a loaded and photoelastically coated object, a notebook with the installed PhotoStress application and an output device, printer [4].

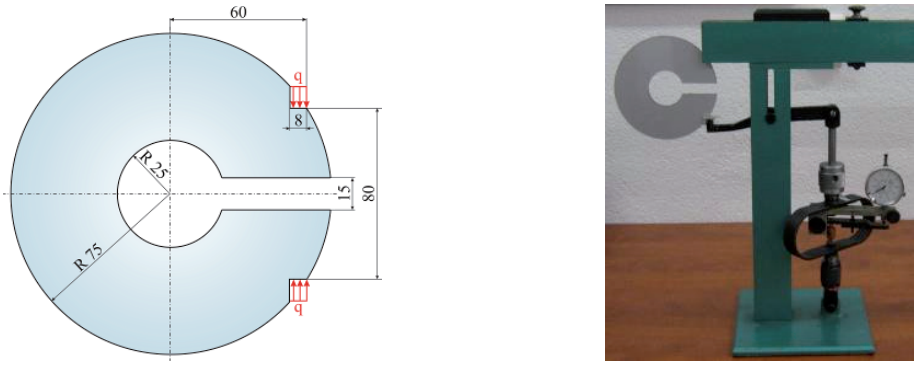


Fig. 3: *Shape, dimensions and character of loading of the partite ring.*

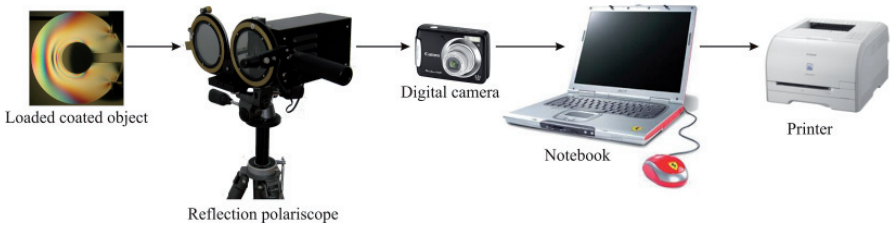


Fig. 4: *Measurement and evaluation chain for determination of stresses by PhotoStress application.*

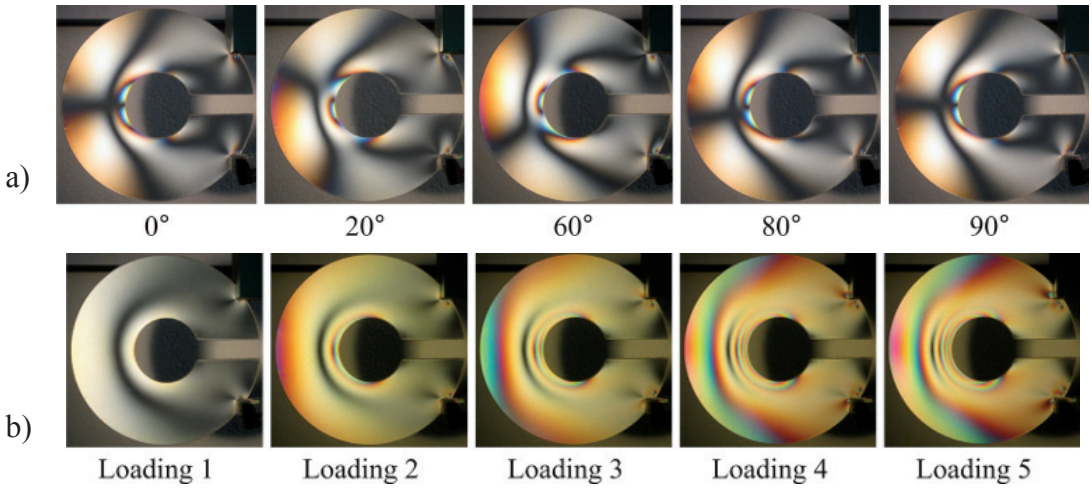


Fig. 5: *a) Some pictures of isoclines; b) Some pictures of izochromatics.*

For computation of the principal strains or stresses it is necessary to create a mask in the PhotoStress application, or to separate the object from the background. Fig.6a shows creation of a mask of the partite ring. The red boundary represents automatic selection on the basis of the edge detection and violet boundary represents manual selection of the edges. The areas that are not important for our investigation are marked by the Red Cross.

In the PhotoStress application the process of creation of isocline lines is simple and very quick (Fig.6b). Isocline lines are drawn manually by a quadratic Bézier curve that is determined by three control points successively for each picture of the isocline lines with a chosen increment, most frequently 10°. After processing individual pictures of isoclines, the whole analyzed field is recomputed by an algorithm for approximation of directions of the principal strains or stresses for every point of the mask. After creation of isocline line bundles and their successive recomputation for individual pixels of the mask, it is possible to show isostatic lines of the I-st and II-nd type (Fig. 6c). Blue curves represent isostatic lines of the I-st type and red curves isostatic lines of the II-nd type.

The process of indexing of color isochromatic fringes is performed in the Isochromes folder. The null or start points are marked (Fig.7a) for algorithms of color determination in individual pixels of the picture and recomputation of the isochromatic fringe order in a given pixels starts. After proper marking of the null points and recomputation, the colors in the whole analyzed area of the investigated object are highlighted (Fig.7b).

After processing osoclines and isochromes, the necessary parameters for photoelastic coating and material of the analyzed object are defined in the folder Test. The application contains predefined material characteristics for the material of the object (steel, aluminium, copper, titanium and brass) and material of the photoelastic coating (PS-1, PS-2, PS-3, PS-4, PS-6, PS-8, PL-1, PL-2, PL-3, PL-6, and PL-8).

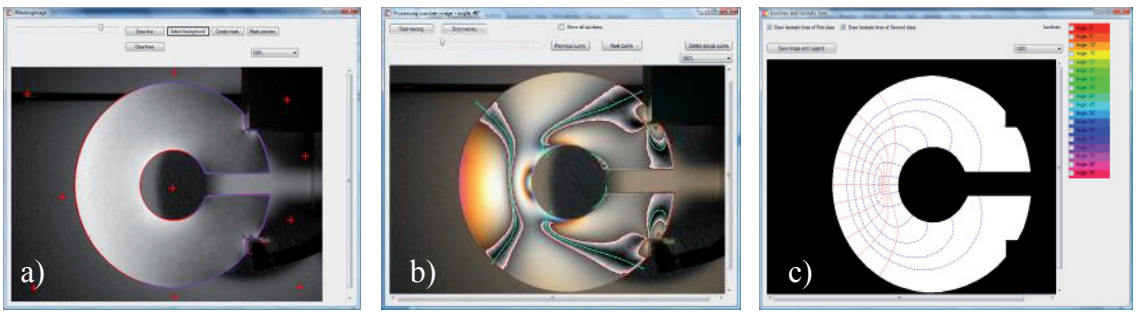


Fig. 6: *a) Creation of the mask; b) Process of creation of isocline bundles; c) Isostatic lines of the I-st and II-nd type on the partite ring.*

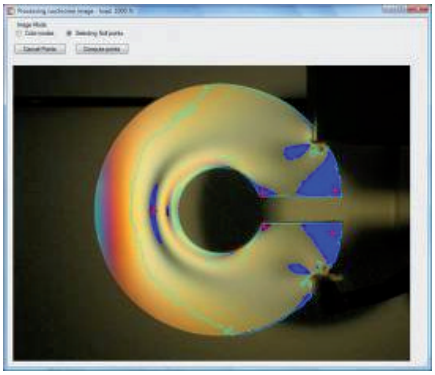
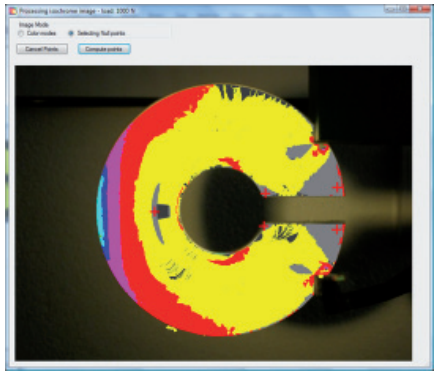
a)  b) 

Fig. 7: *a) Choosing the null points on the loaded partite ring; b) Analyzed region after counting the isochromatic fringe orders.*

The PhotoStress application introduces the term of a region. It is a geometrical entity in which the measurement of directions and magnitudes of the principal strains and principal stresses is carried out. The application offers three types of regions: point, abscissa (line segment), and curve. The region is defined in the folder ROI definition.

The line segment was used for the determination of the principal normal stresses in the partite ring (Fig. 8).

The determination of directions of the principal normal stresses, fringe orders and differences of the principal normal stresses in the defined areas is performed in the folder Results. In this folder it is possible, in case of the abscissa or curve region, to prescribe the number of parts into which the region should be divided. In these boundary points we consequently determine the values of principal stresses, where numbering of points begins with zero. In our case we used 6 equivalent parts (Fig. 8). After this operation of dividing, the resulting values and directions and magnitudes of the principal normal stresses in the points of the region are generated.

Magnitudes of directions of the principal normal stresses are determined by the PhotoStress application in individual points of the line segments (Fig.8) as shown in Table 1.

Points 1, 2, 3, 4 and 5 are inside the area of the coating. The stress state in these points is plane and consequently taking the first measurement in these points we determine only the difference between the principal normal stresses σ1-σ3. Individual components of the principal normal stresses σ1 and σ3

Table 1: *Directions of principal stresses in the points of the chosen region.*

	Region	**Points of measurement**						
		0	1	2	3	4	5	6
Principal direction of stress [°]	Segment	90	90	90	90	90	0	0

Table 2: *Differences between principal normal stresses in individual points of the region.*

Point of region	0	1	2	3	4	5	6
N [-]	0,63	0,45	0,37	0,27	0	0,89	1,44
$\sigma_1 - \sigma_3$ [MPa]	63,43	45,26	37,92	27,03	0	89,57	144,23

Table 3: *Directions of principal stresses in the points of the chosen region.*

Principal normal stress [MPa]	**Points of measuremnet in the line region**							
	0	1	2	3	4	5	6	0
σ1	63,43	43,89	36,91	25,78	9,63	2,47	0	
σ3	0	-1,37	-1,01	-1,25	0	-87,1	-144,23	

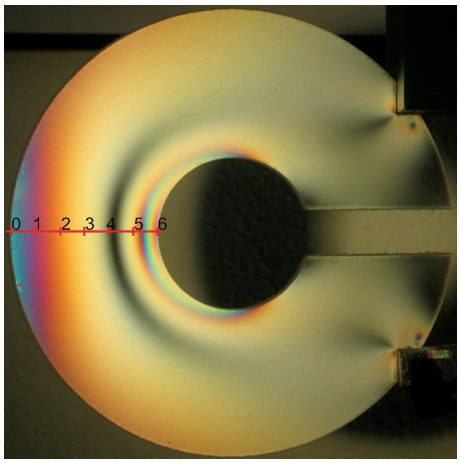


Fig. 8: *Line segment.*

are determined by further measurement using the method of separation. Values of the fringe orders N and differences of the principal normal stresses σ1-σ3 in individual points of the region are given in Table 2.

The Slitting method was used for the determination of individual values of the principal normal stresses in the points of the line segment region that lie outside the free boundary of the coating. In this method, a slit is created through the photoelastic coating in the direction of the principal stresses σ1 and σ3. In the analyzed line region of the partite ring the slit was created along the isostatic line of the II-nd type (outer boundary - neutral axis) and isostatic line of the I-st type (neutral axis – inner boundary) that lie on the axis of symmetry of the partite ring, along the line segment region (Fig.9a, 9b).

Values of the separated principal normal stresses σ1 and σ3 determined by the PhotoStress application are given in Table 3.

Fig. 10 gives a chart of the separated values of the principal normal stresses σ1 and σ3 in individual points of the region using the Slitting method.

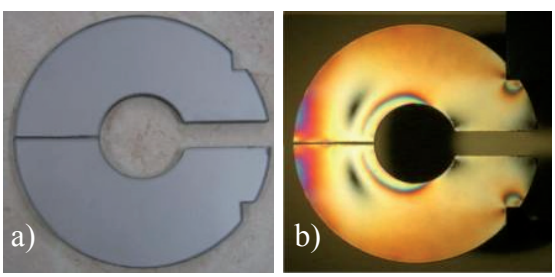


Fig. 9: *a) Unloaded partite ring with a slit; b) Loaded partite ring with a slit.*

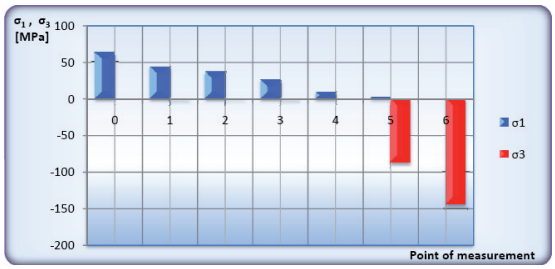


Fig. 10: *Chart of separated values of the principal normal stresses σ1 and σ3 in individual points of the region.*

4. Conclusion

As it is obvious from the example of the determination of directions and magnitudes of the principal normal stresses in the partite ring, the PhotoStress application provides a quick quantitative analysis that gives opportunity to use it not only in laboratories, but also in technical practice. We plan to improve the technique in order to apply it not only to statical, but also dynamical analyses using stroboscopic light and quick cameras. We intend to modify the application for the analysis of residual stresses by the PhotoStress® method using the hole drilling method. Further mathematical methods of separation are being developed for separation of individual values of the principal strains and stresses [9, 10, 11].

The results of subsequent improvements of the software in question, which uses the mathematical theory of elasticity, will be published in proceedings of scientific conferences and journals in Slovakia and abroad.

5. Acknowledge

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