Determination of Damage in Transparent Optically Active Materials by Using Polarized Light and the Sobel Operator

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dabar
DIGITALNI AKADEMSKI ARHIVI I REPOZITORIJI

Determination of Damage in Transparent Optically Active Materials by Using Polarized Light and the Sobel Operator

Case Study

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Abstract – This study deals with determination of the percentage of damage in an optically active, translucent material (polystyrene). We made cracks visible by placing the material into the polariscope (between the polarizer and analyzer), and the numerical value of damage was determined by using Sobel, one of the Matlab's operators for edge detection.

1. INTRODUCTION

Nowadays, a large number of photoelastic materials (such as epoxy resins, polyesters, different kinds of plastic material, plexiglass, ordinary glass, etc.) is used in industry, in everyday life, and in other fields of living. In their manufacture, processing or use, they may suffer permanent damage not visible to the naked eye, but the damage is clearly visible if we put such piece of material between the polarizer and the analyzer. In the cases when it is important to have undamaged material, such material can be checked in a polariscope and the damage may be analyzed by using the edge detection tool. In such case, the numerical amount of damage of the observed sample can be expressed and thus more precise damage evaluation can be ensured.

It is better to exclude damage estimation by "the naked eye" and analyze the damage by using the edge detection tool because it is a cheaper, faster, more accurate estimate of the damage, free from human error and work at any time.

The aim of this study was to determine whether it is possible to identify whether the sample is damaged or not by using the polariscope and the Sobel edge operator.

This paper is organized as follows. Section 2 introduces the nature of light and polarization of light waves. Section 3 and 4 discuss optically active substances and photoelasticimetry. The exposure of digital cameras is explained in Section 5. The Sobel operator is explained in Section 6. Section 7 and 8 introduce the materials and methods used in this paper as well as measurement results which are shown in the tables. The paper concludes with a summary in Section 9.

2. NATURE OF LIGHT AND POLARIZATION OF LIGHT WAVES

Throughout history, the nature of light has long been the subject of studies and discussions of scientists of all kinds [1]. Namely, energy can be transferred by means

of particles and waves. Since light also transfers energy, the question emerged as to whether light is a wave or a swarm of particles.

Albert Einstein put an end to this dispute [2] at the beginning of the last century, when he united these two theories and showed that light may be a wave and a particle and he interpreted the light as a swarm of photons. Nowadays, the dual nature of light is generally accepted.

Light is a transverse wave whose particles vibrate perpendicularly to the direction of wave propagation. Inside the plane that is perpendicular to the direction of wave propagation particles can be dispersed in all directions or only along one direction, so we distinguish between unpolarized, polarized and partially polarized light.

Since natural light does not show polarization, it is called unpolarized light. The crystal (body) which makes unpolarized light polarized is called a polarizer [3], and the other crystal used to analyze polarization of light coming from the first crystal is called an analyzer. There is no physical (chemical) difference between the polarizer and the analyzer, there is only the difference in their role and position while examining polarization.

3. OPTICALLY ACTIVE SUBSTANCES

Certain materials affect the polarization plane direction. Certain organic solutions deflect the polarization plane of light, which passes through the solution by a certain angle. This deflection angle depends on the path of light through the solution and solution concentration. Such substances are said to be optically active.

Fig. 1. Light coming from the laptop does not pass through the analyzer

Liquid crystal displays (LCD) that we use are also optically active substances [3]. The display is composed of two polaroids in a mutually crossed position, with a liquid crystal between them. A flat mirror is placed behind them. The liquid crystal is an optically active substance and it deflects the polarization plane. The rays

of light pass through the analyzer, reflect from the mirror and turn back. The entire screen looks illuminated. If an electric bay is switched on, the liquid crystal loses its optical activity and these spots reflect darkness (figures, letters, etc.). Consequently, it is evident that the monitor of the LCD screen is a source of linearly polarized light. If we place an analyzer of polarized light in front of the monitor and rotate it, in a moment there will be a blackout on the monitor emitting polarized light, then the angle between the analyzer polarization plane and the light polarization plane coming from the laptop is 90° (Figure 1). If we rotate it again for another 90°, the analyzer shall let all the light pass (Figure 2).

Fig. 2. Light coming from the laptop passes through the analyzer

4. PHOTOELASTICIMETRY

An optical method of strain analysis which uses the property of photoelastic materials which exhibit "double diffraction" when strained, i.e. when they become optically anisotropic, is called photoelasticimetry [4]. The size of double diffraction depends on the strain amount and distribution and it can be measured by means of polarized light in polariscopes.

A large number of transparent materials shows a feature of double diffraction under load. Glass, many plastic materials, certain minerals, etc. are photoelastic, but only a small number of these materials are suitable for application in photoelasticimetry. In the condition with no load, the model observed in a polariscope should be dark all over, which indicates that there is no prestressing at any point of the model.

Prestressing may occur in the process of fabrication of a photoelastic material or while using the finished material. The reasons of prestressing are:

- inadequate polymerization,
- frozen temperature strains,
- poor mechanical treatment, and
- edge effect.

Photoelastic materials obtained in the process of polymerization frequently contain prestressing due to a different polymerization degree at different points.

5. AMOUNT OF LIGHT IN A DIGITAL CAMERA

While preparing samples, we used a digital camera Panasonic Lumix DMC-S1 capable of taking photos at the exposition compensation values of -2EV to +2EV.

EV is the value of photo lightness or exposition [6]. The exposition is affected by:
- light exposure time (shutter),
- amount of light (aperture), and
- sensor sensitivity (ISO).

A photo may be called underexposed when it misses details in its dark sections so that the photo seems too dark, and it is overexposed when there are no details in its light sections so that the photo seems too bright. It is difficult to save underexposed and overexposed photos since the information which might be used to fill the planes without details are missing.

The light measuring system in the camera tends to determine the average value of the scene brightness or the brightness of the section it is measuring and, on the basis of such information, it adjusts the shutter speed parameters, display aperture and ISO sensitivity in order to obtain the so-called average gray tone (18% gray). The light meter does not normally know which section of the scene is important to us and if our main motive is overexposed or underexposed, we can compensate the exposure. Exposure compensation is calibrated in the exposure values or EV, where +1EV means that we are compensating overexposure (if the photo is too dark and we wish to lighten it), and -1EV is the compensation of underexposure (if the photo is too light and we wish to make it darker).

6. THE SOBEL OPERATOR

An edge can be defined as "a sudden change of intensity in an image" [5]. The Sobel operator performs a 2D spatial gradient measurement on an image and emphasizes regions of high spatial frequency that correspond to edges. It is used to find the approximate absolute gradient magnitude at each point in an input grayscale image. The operator consists of a pair of 3×3 convolution kernels, as shown in Figure 3.

+1	0	-1
+2	0	-2
+1	0	-1

+1	+2	+1
0	0	0
-1	-2	-1

f_1	f_2	f_3
f_4	f_5	f_6
f_7	f_8	f_9

G_x G_y

Fig. 3. Sobel convolution kernels, Gx (left) and Gy (middle), and an image segment (right) to be operated on with equation (1).

One kernel is simply the other rotated by 90°. Assuming an image segment of the same dimensions as that of the Sobel kernel (as shown in Figure 3), the result of convolution will be:

$$|G| = \left| (f_1 + 2f_2 + f_3) - (f_7 + 2f_8 + f_9) \right| + \left| (f_1 + 2f_4 + f_7) - (f_3 + 2f_6 + f_9) \right| \quad (1)$$

These kernels are designed to respond maximally to edges running vertically and horizontally relative to the pixel grid, one kernel for each of the two perpendicular orientations. The kernels can be applied separately to the input image to produce separate measurements of the gradient component in each orientation (call these Gx and Gy). These can then be combined together to find the absolute magnitude of the gradient at each point and gradient orientation. The gradient magnitude is given by:

$$|G| = \sqrt{G_x^2 + G_y^2} \quad (2)$$

An approximate magnitude is computed for faster calculations by using:

$$|G| = |G_x| + |G_y| \quad (3)$$

The angle of orientation of the edge (relative to the pixel grid) giving rise to the spatial gradient is given by:

$$\theta = \tan^{-1}\left(\frac{G_y}{G_x} \right) \quad (4)$$

In this case, orientation 0 is taken to mean that the direction of maximum contrast from black to white runs from left to right on the image, and other angles are measured counterclockwise from this. Usually, Matlab functions perform some type of morphological post-processing that renders the edges in the image more distinct and sharper than by just using the equations from (1) to (4).

7. MATERIALS

A sample (triangle) of polystyrene was taken for studying. Five samples with damage and five with no damage were selected. A laptop (HP ProBook 6545b) was used as a source of polarized light. At 5 cm from the monitor of the computer (P), parallel to the monitor, was a sample (T), and 30cm away from the monitor there was a lens (O) of the camera (LUMIX, 12.1 MP) and the lens was covered with the analyzer (A), i.e. polarizing foil. The device was arranged as shown in Figure 4.

Since the intensity of damage on the sample changes depending on the angle (α) between the polarizer and the analyzer, each sample was photographed three times: for α=0°, α=45° and α=90°, respectively.

A set of 30 photos consists of five samples with damage and five samples without damage. Each of these ten samples was photographed under three differ-

ent angles between the polarizer and the analyzer and then with the exposure correction of -2EV. Examples of such photos are shown in Figures 5 to 8.
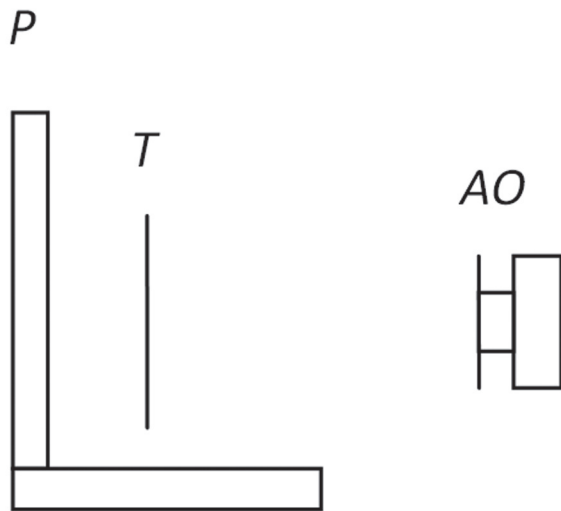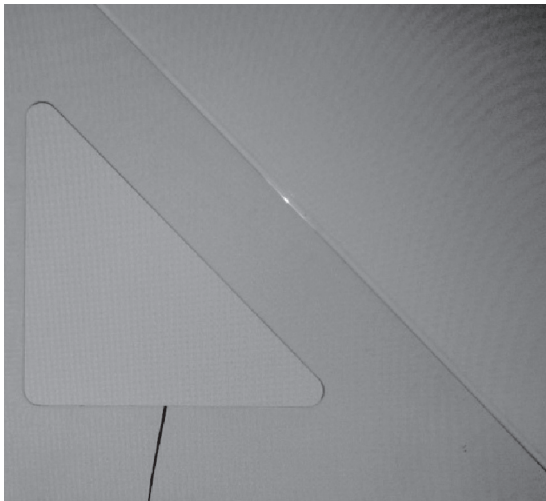

Fig. 4. The device for the analysis of samples
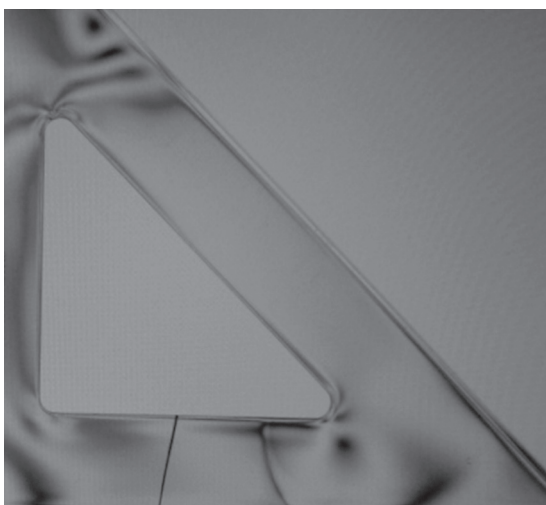

Fig. 5. No analyzer

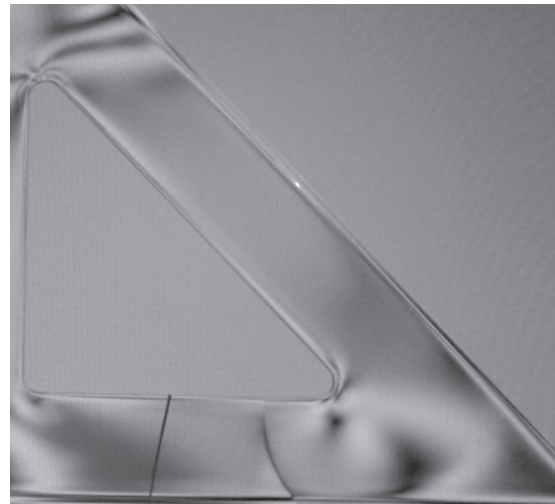**Fig. 6.** The angle between the analyzer and the polarizeris 0°

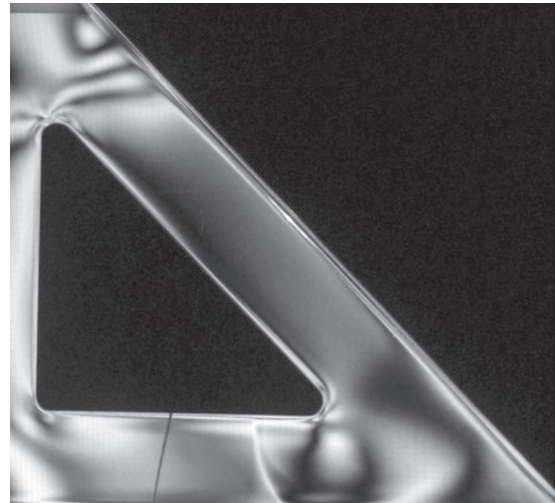**Fig. 7.** The angle between the analyzer and the polarizer is 45°

Fig. 8. The angle between the analyzer and the polarizer is 90°

Figure 5 shows a polystyrene triangle in front of the source of polarized light (LCD monitor) photographed without the analyzer. Figure 6, Figure 7 and Figure 8 are photos of the analyzer condition at an angle of 0° in relation to the polarizer (the lightest monitor), 45°, and 90° (dark background), respectively. This sample is interesting because it has two cracks: one visible with the naked eye (see Figure 5), and the other one which is within the mere triangle structure but the triangle did not break "completely" since there are weak links that keep it together. This crack can hardly or even never be noticed with the naked eye but it can clearly be seen by using a polariscope.

Out of each of these photos (from Figure 6 to 8) two samples were obtained for analysis: one without damage and the other one with damage. Thus, on the basis of five triangles, ten samples were obtained. The observed samples were of rectangular shape but they may be of any shape. Each sample is first converted to the grayscale image which is then analyzed by the Sobel edge detection operator [7]:

```
% image uploading

A=imread('C:\Users\Korisnik\Desktop\
lumix\mini\x4-0.jpg');

% transforming of rgb into grayscale
[8]

IA = .2989*A(:,:,1) +.5870*A(:,:,2)
+.1140*A(:,:,3);

% edge detection

BWA = edge(IA,'sobel',0.06);

% transforming white on black into
black on white

BWA2=1-BWA;

% drawing of found damages

figure; imshow(BWA2); title('sobel');

axis on;

% printing percentage of damaged points

x=sum(sum(BWA));        % number of
points in the damage

y=sum(sum(BWA2));       % number of
points outside the damage

h=(x/(x+y))*100;        % percentage
of damaged points
```

An example of damage found by the Sobel operator in the sample x4-0° is shown in Figure 9.
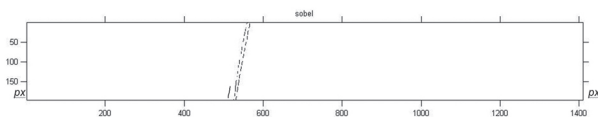

Fig. 9. Damage found by the Sobel operator in the sample x4-0°

The Sobel operator is often used for image analysis which is evident in the wide variety of works:

- This paper consists of contrast adjustments and corrections to the text skew that can occur when scanning. Data entry fields are then identified by using the Sobel operator. [10];
- In this paper, the authors used a web camera for monitoring and the PC with MATLAB environment for managing the parking lot model. The captured frame is first converted to the grayscale image and then to the binary image with the Sobel edge detection method. [11]; etc.

8. METHOD OF WORK

By using photos taken with exposure compensation of -2EV, we made samples in a way that we "cut out" the surplus which was not covered by the analysis and converted such samples into gray color because the loaded photo for each pixel has three components (rgb: one component for red, green and blue color each), and the edge detection operators [9] process only one data per pixel.

The samples with cracks were marked with x1, x2, x3, x4 and x5, and those without cracks with y1, y2, y3, y4 and y5. The results of searching for damages on damaged samples are given in Table 1, and the results of searching for damages on undamaged samples are given in Table 2.

The method of effectiveness determination:

Each sample was photographed at three different angles (0°, 45° and 90°) between the polarizer and the analyzer, since the angle providing the best view of damage on the sample is different for different samples. The largest percentage of damage for each sample was observed (p on samples with a crack, and bp on samples without a crack) so that from damage percentages obtained in such way the lowest percentage (pm) was taken for the samples with damage, and for the undamaged samples the largest percentage of damage (bpM) was taken (marked gray in the Table below).

The goal is to find out the sensitivity threshold of the Sobel operator so that the percentage of damaged points in the undamaged samples is zero or near zero, and the percentage of damaged points in damaged samples is as large as possible, but without unnecessary noise (in this study, the sensitivity threshold with the Sobel method amounts to 0.06). With a larger pm/bpM ratio, the method used is better, and in case the ratio pm/bpM <1, either the method used is not good or it is impossible to analyze the observed material in that way.

Table 1. The percentage of damage in the samples with damage

sobel 0,06	0°	45°	90°	bp
x1	0.1024	0.0077	0.0370	0.1024
x2	0.9009	0.1384	0.0906	0.9009
x3	0.2045	0.0116	0.0505	0.2045
x4	0.1427	0.0665	0.1100	0.1427
x5	0.1523	0.0264	0.0831	0.1523

Table 2. The percentage of damage in the samples without damage

sobel 0,06	0°	45°	90°	P
y1	0.0000	0.0004	0.0000	0.0004
y2	0.0003	0.0021	0.0000	0.0021
y3	0.0009	0.0000	0.0003	0.0009
y4	0.0000	0.0000	0.0000	0.0000
y5	0.0000	0.0000	0.0003	0.0003

$$p_m / bp_M = 48.7619$$

Since the ratio $p_m / bp_M = 48.7619$ (which is much greater than one), it is obvious that this method is efficient for the analysis of this material and that it is possible to verify the damage on the polystyrene by using the polariscope and the Sobel operator for edge detection.

This means that all the defects found in the percentages of damaged samples are greater than any percentage damage in intact samples, which enables a high-quality classification of samples into two groups, i.e. the damaged and the undamaged, and it is possible, without the human factor, to completely objectively assess whether the observed pattern is damaged or not.

The Sobel operator is just one of six Matlab edge detection operators. It would be useful to check how efficient it would be to analyze damage in polystyrene by using other five operators (Prewitt, Roberts, Laplacian, Zero-cross and Canny).

In addition to the change of the operator, it would be useful to apply the aforementioned methods to other photoelastic materials, to compare the methods and see which method is better for what kind of material.

9. CONCLUSION

In this study, it was shown that the cracks which occurred in the structure of transparent optically active materials, which are not visible to the naked eye, can be easily detected by using a polariscope and, together with the naked eye visible defects, efficiently analyzed, and numerically presented by edge detection operator Sobel. This finding is applicable wherever there is a need for undamaged photoelastic materials for their durability, reliability, safety, etc.

In addition to crack determination, one may extend the analysis to the determination of strain in materials and find out the points of maximum strain in transparent photoelastic materials. The analyzer may be used for checking of the quality of built-in monitors functioning on the principle of polarized light (a digital web camera, a digital camera, cell phones, LCD displays, laptops, calculators, etc.), in their casings. Thereby, excessive strain in the monitor would be avoided and longer lifetime of the device and better image quality would be achieved.

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