THE USE OF LASERS FOR SEPARATE DETERMINATION OF STRESSES IN INVESTIGATIONS WITH POLARIZED LIGHT

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Quantum optical generators (lasers) have come into successful use as light sources in the investigation of stresses and strains by polarized light methods (see, for example, [1–4]) because of their high intensity and the monochromatic nature of their radiation, and because of the small divergence of their beam. However, one of the principal special features of lasers, i.e., the coherence of radiation, has not as yet been used in this application.

This paper deals with the use of this particular feature to obtain pictures of isopachs (lines of equal sums of principal stresses in plane elastic models and photoelastic layers), and also to determine absolute differences in path length.

1. **Generation of Isopachs.** As is well known, the polarized light method of stress investigation allows rather simple determination of the direction and differences of quasi-principal stresses. As regards separate determination of these, in spite of the abundance of diverse methods for determining stresses, this area of polarized light investigation remains very difficult and of very low accuracy.

One of these methods, the separation of stresses via isopach pictures, is very simple, if the pictures can be obtained. But it is a very complex matter to obtain these by means of the well known interferometer system, in equipment with ordinary light sources.

Construction of the existing Michelson, Faver, Post and other interferometers (see, for example, [5]) requires high accuracy in fabricating the model and very careful adjustment, and they have therefore not been widely used for investigating transparent models, and have not been used at all for investigating photoelastic layers. The above shortcomings of existing interferometers stem from the fact that ordinary light sources are used in these devices, and therefore interference can be observed only for very small differences in path length between the interacting beams. Lasers produce light that is monochromatic and coherent to an exceedingly high order, and yields sharp interference pictures for the very large path differences enountered in polarization-optical investigation. To carry out the investigations in this case we can use ordinary polarized light equipment for operation in reflected or transmitted light, without complex additional devices. Here the model may be of virtually any thickness.

Equipment of this type is shown schematically in Fig. 1. Here the light from laser 1 reflects from semitransparent mirror 2, and passes through model (or photoelastic layer) 3. One part of the beam reflects from surface a, and the other reflects from surface b of the model and falls on screen 4. The system of lenses 7, 8 serves to increase the beam diameter. In our investigation a type LG-55 helium-neon laser was used, and the analyzer section was taken from IMASh-KB-2 equipment.

If polarizer 5 and analyzer 6 are introduced, the screen will show the interference pattern caused by interaction of the beams reflected from surfaces a and b of the model (or photoelastic layer) in the form of the lines of equal model thickness. This pattern is photographed twice: before and after loading of the model, or at two loading levels. Figure 2 shows such patterns for the case of diametral compression of a glass disk.

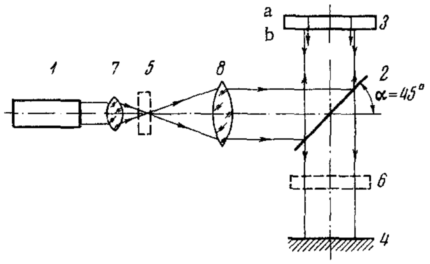

Fig. 1

In addition to the main interference pattern, the screen shows a secondary pattern (less distinct, and easily distinguished from the main pattern), arising from interference from beams reflected from the surfaces of the lenses, the semitransparent mirrors, and so on. To weaken this pattern, coated optics can be used in the equipment (although this is not obligatory).

Experiment shows that in investigations by the photoelastic layer method, the clarity of the pattern is enhanced if an additional reflecting film is glued to the layer surface, on the incident light side, to utilize reflection from the surface of the element to which the layer is attached.

The difference between the two patterns obtained in this way for the different model loadings gives a picture of the isopachs in investigation of elastic plane models and photoelastic layers. In reducing the data the moiré effect can be used when there are sufficient interference fringes on each of the patterns. To achieve this, the two negatives, corresponding to the two loading levels, are combined and printed together on photographic paper. Figure 3 shows isopach patterns obtained in this way for the diametrally compressed disk (a), in centrally tensioned strips with rounded sides (b), and with a circular aperture (c). The isopachs were obtained in plastic sheet specimens without any additional surface processing (usually from 5 to 20 interference fringes are observed per cm of sheet surface, for this material, in the state as supplied). The isopach patterns can also be observed immediately and during the process of loading the model. To achieve this the first negative must be fastened to the screen, coincident with the area of the model.

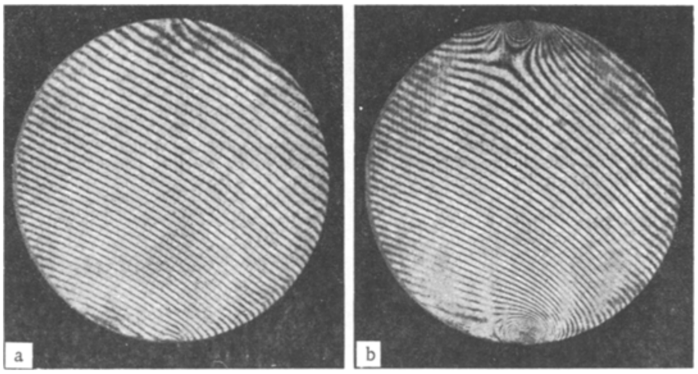

Fig. 2

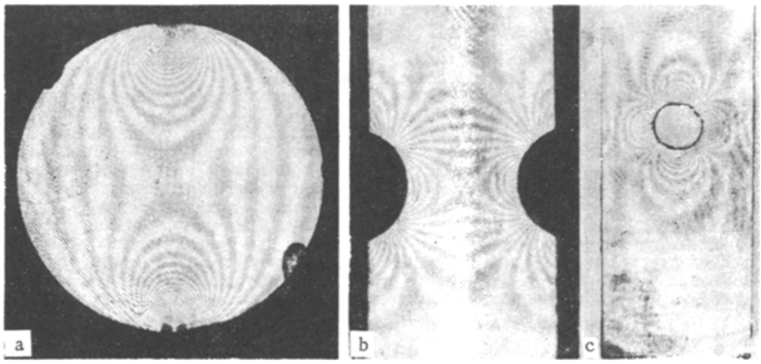

Fig. 3

The order n of the isopach is associated with the sum of the principal stresses $\sigma_1 + \sigma_2$ by the relation

$$\sigma_1 + \sigma_2 = -\frac{E}{\mu}\frac{\lambda}{2d_0}n .$$

Here λ is the wavelength of the light, d_0 is the model thickness, and E and μ are the elastic constants of the material.

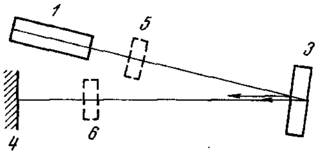

Fig. 4

When we introduce crossed polarizer 5 and analyzer 6, the equipment operates as an ordinary polariscope, and the patterns of the interference fringes on the screen correspond to lines of equal quasi-principal stress differences (fringes) and lines of identical slope (isoclines). In this case no pattern is observed at the layers owing to interference of rays reflected from surfaces a and b of the model, since rays reflected from the outer surface of the model are extinguished by the analyzer. The instrument shown with a V-shaped layer operates in a similar way (Fig. 4).

To obtain isopachs by the above method we must use models made of material with low optical activity, so that the interference pattern arising from variation in model thickness is not distorted by birefringence.

2. Determination of absolute path difference. The equipment described allows us to determine individual values of stresses even when investigating a model made from an elastic material with high optical activity. To achieve this we need only connect polarizer 5 into the circuit (if laser radiation is unpolarized). Before the model is loaded, the interference pattern will correspond, as before, to the lines $n_0 2d_0 =$ $=$ const (n_0 and d_0 are the refractive index and the plate thickness in the unstrained state, respectively). After the model is loaded, interference patterns in the form of lines $n_1 2d_1 =$ const will be observed in the region in which the direction of the principal stresses coincides with the direction of the plane of polarization (i. e., at the isoclines). To obtain these patterns for the entire specimen, transmission is effected with varied positions of the plane of polarization in a way similar to what was done to obtain the fields of the isoclines.

When we have elastic deformation of a plane model or film, the quantities n_1 and d_1 are related to the stresses by the formulas

$$n_1 = n_0 + c_1\sigma_1 + c_2\sigma_2, \qquad d_1 = d_0\left[1 - \mu E^{-1}(\sigma_1 + \sigma_2)\right].$$

Here c_1 and c_2 are optical constants of the material.

The difference between the two interference patterns thus obtained will correspond to the lines $n_1 d_1 - n_0 d_0 =$ const, from which it is easy to find individual values of the principal stresses.

A similar method is used to measure the absolute path difference in frozen sections. For this purpose model 3 (Fig. 1) is replaced by an immersion bath (Fig. 5), one of whose walls, a, is covered with a reflecting layer, while the second wall, b, is semitransparent. The bath is filled with a transparent liquid of refractive index equal to that of the section material.

If the surfaces of the bath were perfectly plane and mounted perfectly parallel to one another, the interference pattern with the polarizer and analyzer parallel (or with the polarizer alone,) would immediately give lines of equal value for the absolute path difference at points in the section in which the directions of the quasi-principal stresses coincide with the directions of the plane of polarization

$$\Delta = [c_1\sigma_1' + c_2(\sigma_2' + \sigma_2')]\, d_0 .$$

Ordinarily we need to photograph the picture twice; once before introducing the section into the immersion bath, and once afterward, and to obtain the lines $\Delta =$ const, we use either the moiré effect, or simple calculation.

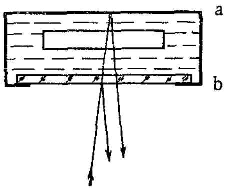

Fig. 5

In a similar way patterns can be obtained even for straight-through illumination of models or sections.

REFERENCES

1. N. Walter and P. Tuisku, "A laser light source in dynamic photoelasticity," Doct. diss. Univ. Hl., 1965.

2. C. E. Tayler, C. E. Bowman, W. P. North, and W. F. Swinson, "Application of lasers to photoelasticity," Exp. Mech., vol. 6, no. 6, 1966.

3. S. S. Penner and O. P. Sharma, "Interaction of laser radiation with an absorbing semi-infinite solid bar," J. Appl. Phys., vol. 37, no. 6. 1966.

4. S. Bateson, J. W. Hunt, D. A. Dalby, and N. K. Sinha, "Stress measurements in tempered glass plates by scattered light method with a laser source," Bull. Amer. Cer. Soc., vol. 45, no. 2, 1966.

5. D. Post, "A new photoelastic interferometer suitable for static and dynamic measurements," Proc. Soc. Experimental Stress Analysis, SESA, vol. 12, no. 1, 1954.

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