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A Photoelastic Coating Technique for Rock Fracture Analysis

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A photoelastic coating technique was used to analyze the strain field in an inhomogeneous specimen of Rockville granite. The determination of the biaxial state of stress at a point requires approximately one minute. Preliminary results indicate that mineral textures control the distribution of the strain field and subsequently the fracture pattern of the specimen.

INTRODUCTION

Rock is a very complicated material. Many attempts have been made to study its behavior by theories developed for ideal materials. These attempts have met with little success, especially in the area of rock fracture analysis. It has been demonstrated that rock fracture in compression is a result of the coalescence of multiple cracks aligned in favorable directions [1]. Therefore, a continum theory will, at best, predict the initiation of these multiple cracks. However, the propagation and coalescence of these cracks are the dominant events in rock fracture processes. The stress fields induced by these dynamic events are difficult to obtain by elastic theories because of the constant change of complicated boundary conditions. Furthermore, the propagation of cracks is often controlled by local geological structures that are extremely difficult to incorporate in elastic analytical formulations.

The photoelastic coating technique seems to have good potential in monitoring the strain field of the specimen continuously all the way up to complete fracture and serves as one of the best tools available for tracing the fracture sequence [2,3]. It is, however, very tedious and time-consuming to obtain the complete strain field with the conventional photoelastic coating technique. Among other things, the use of an oblique incident adaptor requires a highly skilled operator because the field of view is very small and the light path is such that it generally creates high glare at the measuring point. However, the availability of digital strain readout and plotters highly facilitates data acquisition and analysis.

This paper presents the development of a modern photoelastic coating technique for rock fracture analysis. It emphasizes the adaption of commercialized equipment and discusses some preliminary results.

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EXPERIMENTAL TECHNIQUES

The testing system included a test machine for applying a load, and a reflection polariscope with automatic data acquisition devices. The loading machine was a servocontrolled closed-loop pressurization system. Its operational principles had been described elsewhere [1]. The reflection polariscope (Fig. 1) consisted of two polarized-quarter wave plate assemblies which were ball-bearing-mounted to a common frame so that the two assemblies would rotate simultaneously. A uniform field compensator, attached to the analyzer ring, was provided for determining the values of fractional fringe order. The system also included an oblique incidence adaptor for producing oblique incidence light on the specimen. The data acquisition system consisted of a strain reader that displayed strains in μin/in, and a printer that provided a printout of strain magnitudes, point numbers and principal strain direction angles. Figure 1 shows the reflection polariscope with digital strain readout and printer. The complete testing procedures, including the calibration of plastic, followed those suggested by the manufacturer [4] except that the reflection polariscope was mounted on a self-made arch support instead of being mounted directly on the tripod. The arrangement allowed the reflection polariscope to make a 360° turn when the oblique incident adaptor was used. Also shown are special platens on both ends of the specimen which provided ample working space for the oblique incidence when mounted on the testing machine for testing.

Prismatic specimens, $3/4 \times 2 \times 3$ in. in size, of Rockville granite were used in this research. Rockville granite is composed of mostly large grain-size (3–15 mm) feldpar, quartz and biotite on a few fine grains and matrix (0.5 mm) of apatite, zircon and chloride. Most mineral grains are irregular in shape, and fine grain minerals usually fill up in the voids at the grain boundaries formed by large grain-sized minerals (Fig. 2). Rockville granite has an average uniaxial com-

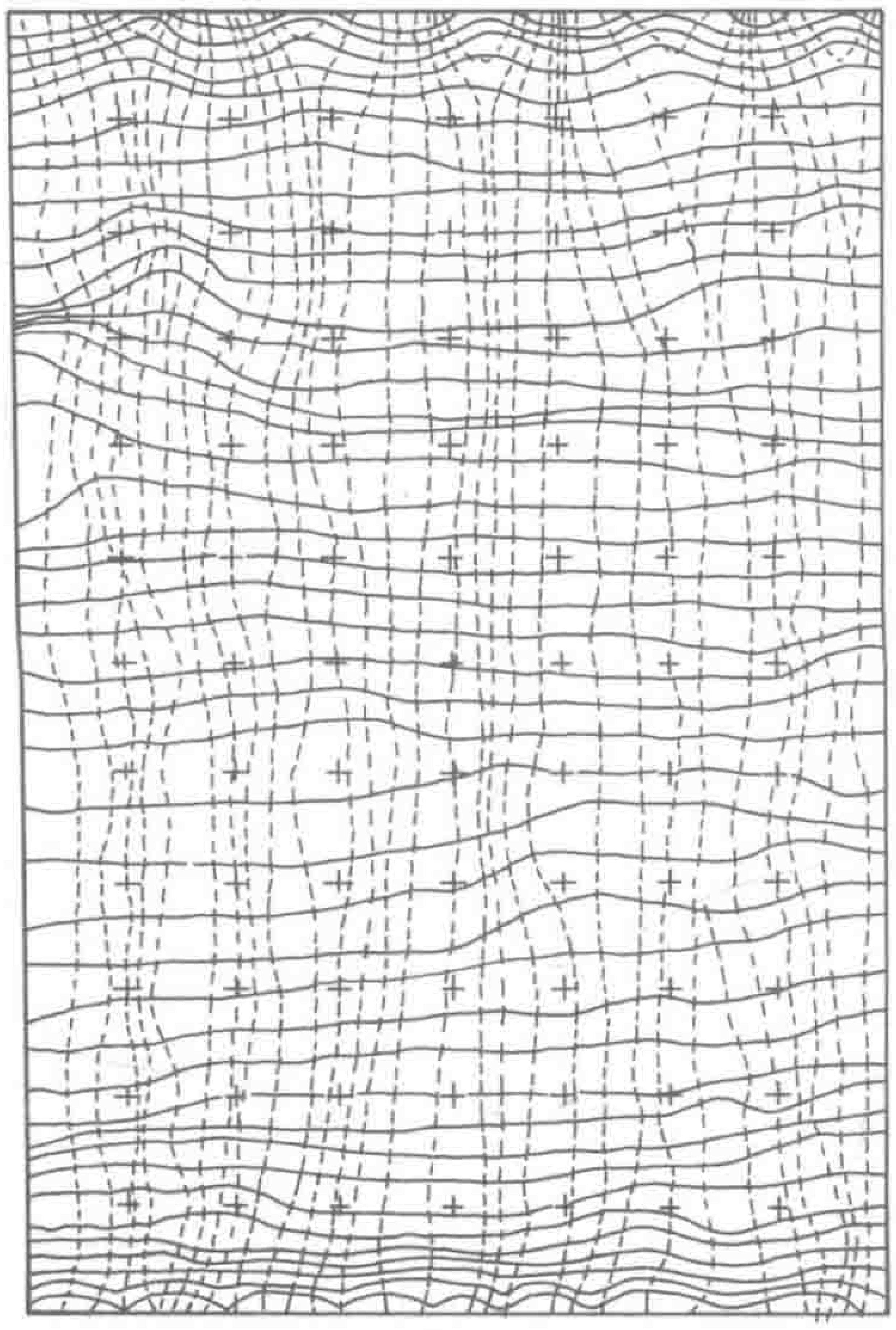

Fig. 4.

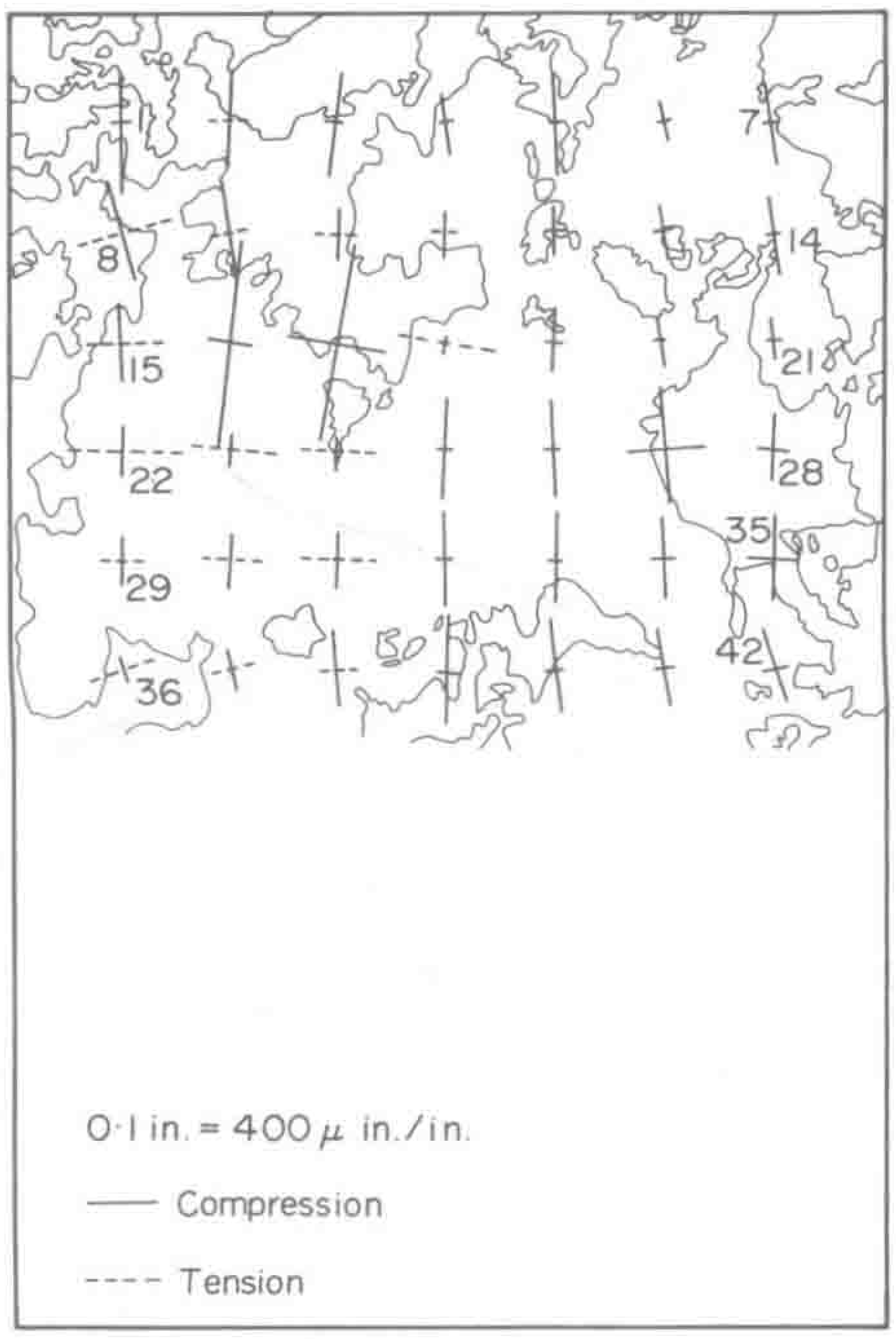

Fig. 5.

approximately 30% of the ultimate strength. At each nodal point, the normal incident light was first used to determine the directions of principal strains and the magnitudes of maximum shear strain ($\epsilon_x - \epsilon_y$) through the analysis of the isoclinic and the isochromatic, respectively [4]. The oblique incident light adaptor was then used to obtain the fringe order such that:

$$N_0 F = (A\epsilon_x - B\epsilon_y), \qquad (1)$$

where N_0 is the fringe order by oblique incident light, F is the fringe value of photoelastic coating, and A and B are constants. When the oblique incident angle, θ, is small, $A = B = 1$, and equation (1) reduces to that used for normal incidence measurements,

$$N_0 F = \epsilon_x - \epsilon_y. \qquad (2)$$

The principal strains at any point for $\theta = 55^\circ$ can be obtained from equations (1) and (2) by Redner [5]:

$$\epsilon_x = F\,(1.5\,N_0 - N_0),$$
$$\epsilon_y = F\,(1.5\,N_0 - 2\,N_0). \qquad (3)$$

This operation of determining the directions and magnitudes of principal strains took approx one minute and was repeated for each nodal point in the specimen. Figure 5 shows the complete information obtained by this operation. The directions and length of the mutual perpendicular lines indicate the directions and magnitudes of maximum and minimum principal strains, respectively. The relative configuration of mineral grains is also shown for comparison.

EXPERIMENTAL RESULTS

Stress analysis of an elastic homogeneous prism subjected to uniaxial compressive loading [1] indicates that extremely non-uniform stress distribution occurs in the vicinity of the specimen-end surfaces especially those at the corners. The stress distribution becomes more uniform toward the interior of the specimen. Thus stress distributions in the middle one-third of the specimen are rather uniform, and the axial stress is approximately equal to the average applied stress at the end surfaces. Tensile tangential stress also occurs in areas close to the lateral surface, but the magnitude is very small as compared to that of axial stress. It is also true that the characteristics of strain distributions will be similar to that of stress distribution in an elastic material.

As expected, the photoelastic coating technique shows that the strain field in a Rockville specimen subjected to uniaxial loading is highly non-uniform. There are variations in strain types (tension or compression), magnitudes and directions of principal strains from point to point. The major principal strains are all compressive. Their magnitudes range from 100 μin/in to 2800 μin/in when the average axial strain is 640 μin/in as measured by an extensometer over the full length of the specimen. The orientation of the maximum principal strain falls between -22 degrees and $+10$ degrees of the vertical (axial) direction, i.e. the direction of load application. Most of the major principal strains ($>75\%$) rotate counterclockwise. The variations in the characteristics of major principal strains from point to point do not follow any mathematical trend but depend highly upon local geological structures. Higher variations occur at points located at and/or close to the grain boundaries of grains with large elastic contrast. The largest variation occurs from grid point No. 16 to No. 18 which corresponds to the maximum (2800 μin/in) and minimum (100 μin/in) major principal strain, respectively. Notice grid No. 17 is at the grain