Temperature and Time Influence in the Stress Freezing of the Epoxy Hysol 4290

Object of this research is to supplement previous investigations of the mechanical and optical properties of Hysol 4290, as an aid to those who use the material to "freeze" the photoelastic response

by V. J. Parks, T. L. Chen and A. J. Durelli

ABSTRACT—Disks of the photoelastic epoxy known as Hysol 4290 have been subjected to constant load at various temperature levels and the birefringence has been recorded as time elapsed (creep test). Also disks of the same material were loaded at the critical temperature (creep test) and then cooled, each to a different temperature level and, after they reached thermal equilibrium, the loading was removed while the temperature was maintained constant (recovery test). The effect of time on the fringe value is given for both groups of tests using the temperature as a parameter. Finally, tensile specimens have been subjected to various loads at the critical temperature and fringe response and failure recorded. The results obtained may be useful for the design of experiments and, in some cases, to shorten the time required to conduct a three-dimensional photoelasticity investigation using the "freezing" method.

Introduction

One of the authors began using Hysol CP-5 4290 more than ten years ago when it was called 6000-OP, at the suggestion of a representative of the Hysol Corporation, who indicated that the product was available in sheets and rods. Today it is used by many investigators but, aside from the company's brochure, only two references 1, 2 have been found in the literature reporting some of the material properties. It is the object of this research to supplement the previous investigations of the mechanical and optical properties of Hysol 4290, as an aid to stress analysts who use the material to "freeze" the photoelastic response. The material property of particular interest in this study is the birefringent response.

Photoelastic materials, in general, exhibit some viscoelastic properties so that their behavior is influenced by the length of time the material is loaded and by the temperature. The most marked variation of the properties occurs in a temperature range called the transition zone, which divides the cooler state of the material at which it has a hard consistency (glassy state) from the hotter state of the material at which it is softer (rubbery state).

Viscoelastic studies show that, for materials which satisfy certain conditions, the variation of several properties with temperature can be related in a simple way to the duration of the load. This relation is usually expressed by plotting first the material property at a given temperature (T₀) as a function of the length of time (in log scale) that the material is subjected to load. It can be shown, then, that a second plot of the same material property, obtained at another temperature (T), when multiplied by the temperature ratio (T/T₀) will have the same shape as the one obtained for T₀. The only significant difference between the two curves is seen to be a constant distance along the time axis. This distance is called the shift for the temperature T.

By plotting the amount of shift for various temperatures, a shift-temperature curve and one property-time curve (called a master curve) are sufficient to define the material property throughout the range of temperatures and times of loading.

In one of the contributions mentioned above 1 Brinson reports the stress-fringe value and Young's modulus of Hysol 4290 over the glassy-state transition-zone-rubbery-state range using the master-and shift-curve description. He also reports the glass-transition temperature as determined by a change in the thermal coefficient of expansion of the material. In this paper the variation of stress-fringe value is reported using direct measurements at all temperature levels without recourse to a shift principle and, therefore, without having to make assumptions on the material behavior. This has also the advantage of presenting the data in a more practical way for application to stress analysis using the freezing method.

Additional properties of interest that are reported in the paper are the fringe value remaining after unloading, the influence of temperature rate on birefringence in loading and unloading, and the proportional limit and failure stress.

Linear Viscoelastic Behavior in Photoelastic Materials

Most photoelastic materials below certain threshold limits of strain behave in a linear manner. Sometimes, as in the case of the rubbery state of epoxies, the response is practically instantaneous. In general, they behave viscoelastically, but the response in most of these materials is still linear as a function of load 3 and, therefore, all that is required for an analysis is a calibration as a function of time, at the temperature of the test, or for the range of temperature at which the test is conducted. Taking advantage of this fact, photoelastic studies have been conducted using the creep-in response of the material 4 as an alternative to the use of the freezing method. This property has also been used to an-
alyze elastic shrinkage stresses by recording the integral response of a material subjected to restraint as it cooled through the transition zone. In each of the studies cited, the method was checked by applying a load to a specimen of simple geometry for which the elastic solution was known theoretically. These cases are brought up to emphasize that, as long as the photoelastic material is known to be linearly viscoelastic, it is not necessary to load it above the transition-zone temperature to conduct an elastic analysis. It is only necessary to use a combination of temperature and loading time which will give the required response.

It is important, however, that the mechanical and optical properties of the material be known over the range of temperature used. In addition, the temperatures that bound the transition zone should be known. These are referred to below as the upper and lower critical temperatures. Experience indicates that at least the more important properties should be obtained by calibration for each individual analysis, due to the variation between batches of the same material.

The Freezing Method

The "freezing" method in three-dimensional photoelasticity usually requires a long temperature cycle. The thicker the specimen investigated, the longer this cycle is and, in the experience of the authors, it is frequently as long as a month. This is undesirable, since the laboratory equipment is tied up all that time. It is also undesirable because, for at least half the length of time in the oven, the material is subjected to load, and static fatigue weakens the plastic.

It would be desirable to use the "freezing" method below the critical temperature and shorten the duration of the test. To decide whether this is possible, it is of importance to determine, at several temperatures below the critical, the length of time that is required for the specimen to reach the photoelastic response that it would have reached if loaded in its rubbery state. Creep tests at different temperature levels provide this information.

Even if a shorter temperature cycle is not adopted, it would be desirable to know when a loading failure in the down part of the cycle invalidates the results. A typical practical problem which may occur is the following. Consider the specimen that, after being loaded to the upper critical temperature, is slowly cooled to room temperature. Suppose that the loading fails during cooling, as would be the case when a leak develops in the system used to load a pressure vessel. The question to be answered is whether the frozen deformations observed at room temperature are representative of the state of stress in the rubbery state; or, in other words, will the fringe patterns be altered due to load failure as the temperature is decreasing? In order to answer this question, it is necessary to know, for a given rate of temperature change, the temperature at which the fringe patterns are practically "frozen," i.e., below which the response is not altered essentially any more.

The test program reported here is an attempt at the solution of this and similar problems.

Description of Experiments

The tests were conducted in an oven with stress-free glass windows in front and back. The specimens were all cut from the same sheet of Hysol 4290 and were annealed after cutting. The temperature in the oven was uniform ±1°F. Elements of the polariscope were located on each side of the oven so that the optical axis of the polariscope passed through the windows.

Disks, 1 in. in diameter and 1/4-in. thick, were diametrically loaded with 5-lb weights in a loading frame which has nine loading positions staggered in two rows. The fringe order at the center of each