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A COMPARISON OF STATIC AND DYNAMIC PROPERTIES OF PHOTOELASTIC MATERIALS

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ABSTRACT

The dynamic values of the modulus of elasticity and photoelastic fringe constant of Homalite 100 and ten epoxy resins were determined. Of these eleven materials, it was found that five exhibited desirable dynamic properties including two materials which exhibited no appreciable change in fringe constant. Consequently a static calibration on these materials can be used for dynamic experiments with a high degree of accuracy. Included in this group of five materials were three materials which can be purchased in precast shapes, thus enabling laboratories without casting facilities to obtain suitable materials for dynamic photoelastic experiments.

PROBLEM STATUS

This is an interim report on one phase of the problem; work on this and other phases is continuing.

AUTHORIZATION

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SYMBOLS

E = modulus of elasticity, psi

f = fringe constant, psi-in./FR

L = longitudinal strain per fringe, μin./in./FR/in.

m = mass of the throw-off bar, slugs

v = velocity of the throw-off bar, ft/sec

$\sigma(t)$ = time variation of stress, psi

$\epsilon(t)$ = time variation of strain, μin./in.

A = cross-sectional area, in.^{2}

ρ = mass density, slugs/ft^3

V = velocity of sound in the material, ft/sec

pphr = parts per hundred of resin

t = time, sec

T = period of impulse, sec

$F(t)$ = time variation of the impulse force

s = subscript denoting static value

d = subscript denoting dynamic value

A COMPARISON OF STATIC AND DYNAMIC PROPERTIES OF PHOTOELASTIC MATERIALS

INTRODUCTION

The increasing importance of photoelasticity as an experimental tool in dynamic stress analysis has led the authors to a continuation of the original investigation of CR-39 (1)* to include a number of new photoelastic materials developed within the past five years. The results of these experiments indicate that there are presently available at least several materials which exhibit little or no change in photoelastic properties with increasing loading rate.

It should be noted that the properties of photoelastic materials are dependent on many variables and may vary considerably between castings; therefore, the values presented in this report are only typical values obtained from a single casting. However, since considerable care was taken in the preparation of the specimens, it is believed that the reported values are representative of the materials prepared according to the manufacturers' recommendations.

GENERAL PROCEDURE

A longitudinal compression wave was introduced at one end of a long, square bar of the material under investigation by the impact of a projectile. At a gage site on this bar the two effects of the wave were observed simultaneously: the strain-time relation on the surface of the bar using etched-foil strain gages, and the corresponding time variation of the photoelastic fringe order observed with a photomultiplier tube. Separate cathode-ray oscilloscopes were used to record these two signals.

A direct comparison of the calibrated strain vs time curve with the fringe order vs time curve resulted in the dynamic value of longitudinal strain per fringe. The dynamic modulus of elasticity of the material was computed from†

$$E_d = \frac{mv}{A \int_0^T \epsilon(t)\, dt}$$

where

$$\int_0^T \epsilon(t)\, dt$$

is the area under the strain vs time curve.

An alternate method of determining the modulus of elasticity was also used based on the sound velocity:

$$E_d = \rho V^2 \ .$$

*Numbers in parenthesis refer to references listed at the end of this paper.
†See Appendix A for the derivation of this equation.

EXPERIMENTAL METHOD

The essential elements of the apparatus are shown in Fig. 1. The specimen was a bar approximately 1/2 inch square and 13 inches long. The bar rested on Teflon rollers mounted onto positioning rings in a long vee channel. Cradled in the same channel so as to have a horizontal axis common to that of the bar, a 0.30-cal. gun was arranged to fire a pointed projectile 0.300 inch in diameter, 1-1/2 inches long, having a 4-cal. ogive nose or a tapered nose with an included angle of 30 degrees. The projectile impinged on a soft metal cap (2-S aluminum) 1/2 inch thick having the same cross section as the bar. This cap served both to protect the front end of the bar and to provide a ductile material in order to produce a smoothly increasing loading force during the partial penetration of the sharp nose of the projectile. A smooth loading wave is necessary to allow resolution of successive fringe orders. In addition, a smooth wave spread out over 100 microseconds assures that the longitudinal wave will propagate as a plane stress wave. A second plastic bar (throw-off bar), abutting the back end of the measuring bar, collects the momentum in the loading wave, thus preventing gross translation of the measuring bar as a result of the impact. The velocity of the throw-off bar is measured and its momentum is computed for use in determining the modulus of the material

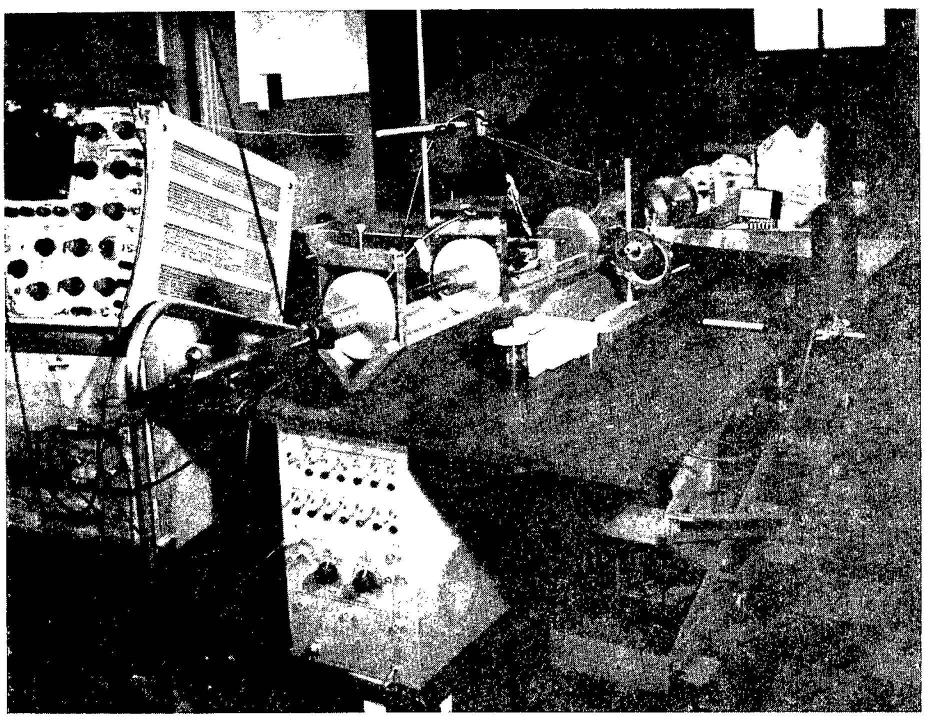

Fig. 1 - Gun, projectile timer, specimen bar, throw-off bar, throw-off bar timer, and supporting structure

The variation in strain was recorded with two etched-foil strain gages (Tatnall Metalfilm, C9-141; 1000 ohms; gage factor 2.04 or 2.06; gage length 1/4 inch) positioned on opposite sides of the test bar at a point 4 inches from the front end of the specimen. The gages were attached to the bar with Eastman 910 cement using an accelerator furnished by the Baldwin-Lima-Hamilton Co.

The gage circuit consisted of a 90-volt battery, the two gages in series, and a 10,000-ohm resistor. The total resistance connected across the 90-volt battery was thus 12,000 ohms, permitting approximately 7.5 milliamperes to flow through the gages. The y-input terminals of a Tektronix 535 cathode-ray oscilloscope were connected across the load resistor. Calibration of the gages was provided by recording the deflection resulting from shunting the gages with a known resistance through a set of motor driven points. The calibration markers (Fig. 2a) are for changes in resistance of 15.88 ohms and 31.5 ohms.

The velocity of the projectile was measured over a 6-inch base length, with the pad on the end of the bar forming the contact for the stop screen as well as initiating the oscilloscope sweep.

The optical photoelastic recording system for the fringe trace is also shown in Fig. 1. The light source was a small sodium vapor lamp, operated on ac for standby but switched to dc for the tests. A wedge of Lucite was used to form a narrow beam of sodium vapor light from the large area of the lamp. Polaroids and quarter wave plates, arranged as a standard circular polariscope, were secured to the sides of the bar with black electrical tape; the tape also served to define the boundaries of an optical slit about 1/16 inch wide. The intensity modulation resulting from passage of the fringes was detected by a photomultiplier tube, type 931A, with the output fed directly to the y-deflection amplifier of a cathode-ray oscilloscope (Tektronix 535). An example of a typical strain oscillogram and the corresponding trace of intensity fluctuations is shown in Figs. 2a and 2b.

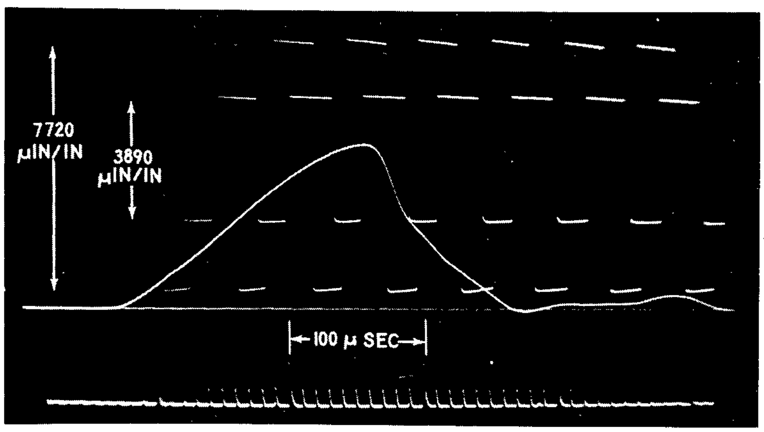

Fig. 2a - Typical strain vs time oscillogram for Hysol 4290, including the calibration signal for the gages

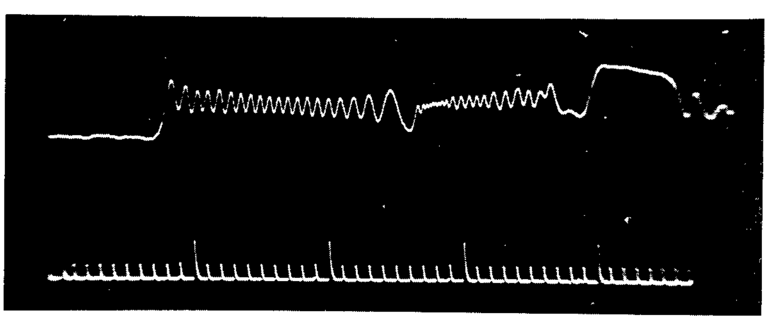

Fig. 2b - Fringe order vs time oscillogram corresponding to Fig. 2a

In the earlier work (1) using wire resistance strain gages, it was found that, when used on CR-39, these gages indicated only 75% of the true strain. The etched-foil gages used in these tests were compared with Tuckerman gages and indicate from 92% to 98% of the true strain in the materials tested.

The static properties were obtained from the same specimen used for the dynamic test loaded in tension. Strain measurements were made with Tuckerman optical strain gages.

RESULTS

The results of this investigation are listed in Table 1. The dynamic fringe constant (f_d) was obtained from the product of the dynamic modulus (E_d) and the dynamic longitudinal strain per fringe (L_d). The static longitudinal strain per fringe (L_s) was obtained from the ratio of static fringe constant to the static modulus. The loading time for dynamic tests was approximately 200 microseconds and for static tests about 300 seconds. Thus the ratio of static to dynamic loading time was 1.5 million.

Table 1
Comparison of the Static and Dynamic Properties of Some Photoelastic Materials at Room Temperature

Material	Casting Temperatures		Modulus of Elasticity, E		Longitudinal Strain/Fringe,* L		Fringe Constant,* f	
	Gel (°C)	Cure (°C)	Static (psi)	Dynamic (psi)	Static (μin./in./FR/in.)	Dynamic (μin./in./FR/in.)	Static (psi-in./FR)	Dynamic (psi-in./FR)
Araldite 6020 w/45 pphr 901	115	120	520,000	535,000	142	149	74	80
Araldite 6020 w/10 pphr CL	80	150	465,000	490,000	133	148	62	73
Araldite 502 w/8 pphr 951	Room	Room	350,000	470,000	220	204	77	96
Araldite 502 w/10 pphr 951	Room	Room	405,000	495,000	195	196	79	97
Araldite 502 w/30 pphr 901	80	80	355,000	515,000	197	160	70	82
Araldite 502 w/43 pphr 901	80	80	460,000	600,000	161	142	74	85
Araldite 6060 w/30 pphr 901	105	110	485,000	535,000	140	128	68	68
Epon 826 w/10 pphr CL	80	150	490,000	515,000	143	153	70	79
Hysol 4264	Precast		480,000	510,000	138	137	66	70
Hysol 4290	Precast		475,000	530,000	137	126	65	67
Homalite 100	Precast		510,000	645,000	302	236	154	152

*Monochromatic sodium vapor light (5893 A).

Notice also that the longitudinal strain per fringe is the reciprocal of the figure of merit (Q) as defined by Leven (2).

Of the eleven materials tested,* the five listed below are best suited for dynamic experiments.

*Appendix B lists the manufacturers.

Araldite 6020 w/45 pphr 901 – This material, already widely used for two- and three-dimensional static analyses, exhibits favorable dynamic properties. The negligible increase in modulus (3%) and small increase in fringe constant (8%) enable dynamic calibration to be made from static tests with a high degree of precision (even if the exact loading rate is not known) by applying a small correction factor to the static results.

Araldite 6060 w/30 pphr 901 – The static properties of this material, widely used in Europe under the designation Araldit B,* have been studied by Baud and Racké (4). Although the modulus increases by 10%, a corresponding decrease in the longitudinal strain per fringe results in no change in the fringe constant. In addition to these desirable properties, this material is easily machined (with the aid of a coolant).

Hysol 4264 and 4290 – These two materials are available in precast sheets, rods, and tubes from the manufacturer. Both have similar properties except for the longitudinal strain per fringe, which is nearly constant for 4264 but decreases by 9% in 4290. Both are easily machined.

Homalite 100 – This material, unlike the others tested, is not an epoxy and has considerably less sensitivity than the epoxy resins. However, since it is available in clear, polished sheets, it is valuable for two-dimensional studies where sensitivity is not of utmost importance. The fringe constant undergoes little change (-1%) from static to dynamic loading. On the other hand, the modulus increases by 26% for a similar change in loading rate. Therefore, this material is less desirable than the others tested in applications where a change in the modulus of the material would be an important factor.

The results of these tests indicate that there are presently available a number of materials for which static calibration can be used for dynamic experiments with a high degree of accuracy even if the exact loading rate is not known precisely. Suitable materials are available both as precast sheets and as casting resins; therefore, with the introduction of these new materials and new techniques it is now possible for photoelastic laboratories of any size to perform dynamic experiments.

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*European designations are (3): Araldit B = Araldite 6060, Araldit F = Araldite 6020, Araldit D = Araldite 502.

APPENDIX A

DERIVATION OF THE DYNAMIC MODULUS EQUATION

In a unidirectional stress field:

$$\text{static modulus} = \frac{\sigma}{\epsilon} = E_s \ .$$

Similarly the effective dynamic modulus, E_d, can be defined as

$$\frac{\int_0^T \sigma(t)\, dt}{\int_0^T \epsilon(t)\, dt} = E_d \ .$$

But $\sigma(t) = F(t)/A$. Therefore

$$\frac{\int_0^T F(t)\, dt}{A \int_0^T \epsilon(t)\, dt} = E_d \ .$$

Since

$$\int_0^T F(t)\, dt$$

is the impulse introduced into the specimen by projectile impact,

$$\int_0^T F(t)\, dt = mv$$

is the momentum transferred to the throw-off bar. Hence

$$\frac{mv}{A \int_0^T \epsilon(t)\, dt} = E_d$$

where

$$\int_0^T \epsilon(t)\, dt$$

is obtained by graphical integration of the strain vs time oscillograph record.

APPENDIX B

MANUFACTURERS OF THE MATERIALS TESTED

Manufacturer	Product
Ciba Products Corporation Fairlawn, New Jersey	Araldite 502, 6020, 6060, HN901, HN951
Shell Chemical Company New York, New York	Epon 826, CL Hardener
Hysol Corporation Olean, New York	4264, 4290
Homalite Corporation Wilmington 4, Delaware	Homalite 100