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A Noncontacting, Short-Gauge-Length Technique for Measuring Strains on Plastics

INTRODUCTION

There are many experimental situations requiring a strain measurement over a short gauge length, e.g., dynamic experiments in which dispersive stress waves propagate in the specimen. For tests with metals, this demand is often satisfied by the use of foil-resistance strain gauges. Unfortunately, it is difficult to use such gauges on plastics for the following reasons:

1. It is sometimes difficult to bond the foil gauge to the plastic.
2. The current passing through the resistance gauge heats the area surrounding the gauge causing local variation in material properties and variation in gauge response. This effect may be reduced by using a smaller current, but such a procedure also reduces the sensitivity of the measurement. Another recent method that reduces, but does not eliminate, the heating difficulty is to use a short pulse of current in the gauge.
3. The gauge, consisting of a metal alloy foil approximately 0.0001 in. thick and an epoxy carrier about 0.0005 in. thick, can reinforce the sample causing erroneous readings. This situation is particularly true for small samples or soft plastics.

This note describes an optical technique of measuring strain in a noncontact manner over short gauge lengths. It removes the latter two of the above disadvantages, but it is occasionally difficult to apply the gauge directly to some materials. A typical direct-gauge application to poly(methyl methacrylate) (PMMA) for dynamic strain measurement is presented. A typical application to another plastic-type material is also described that utilizes a method of indirect gauge attachment.

INTERFEROMETRIC STRAIN MEASUREMENT

The basic principle of the interferometric strain gauge (ISG) technique can be explained with the aid of Figure 1. Two very shallow wedge-shaped grooves are ruled close together onto the surface of the sample normal to the direction of strain. These grooves are typically 0.0004 in. deep and 0.005 in. apart. The sides of these grooves must be reflective to the incident radiation. If coherent monochromatic radiation from a laser operating in the TEM_{00} mode is reflected from the sides of grooves A and B (the dimensions of these sides are small enough to cause appreciable diffraction of the light), interference fringe patterns will be formed at L and R because of differences in path lengths. The position in space of these patterns is related to the spacing of the grooves as well as to the rigid body motion of the sample. If rigid body motion is neglected, the strain ϵ in the sample is related to the fringe motion by[1]

$$\epsilon = \frac{(\Delta F_L + \Delta F_R)\lambda}{2d_0 \sin \alpha_0} \tag{1}$$

where ΔF_L and ΔF_R are the number of fringes passing the observation positions for patterns at L and R, respectively, λ is the wavelength of light used, d_0 is the original distance between grooves, and α_0 is the angle between the incident beam and the observation positions. Details of this technique may be found in references 1 and 2. Although the discussion in this paper is applied specifically to dynamic studies, nothing precludes application to quasistatic investigations.

In practice, rigid body motion cannot be neglected, but its most predominant effects can be removed by averaging. If we define fringe motion toward the incident laser beam as positive, tensile strain gives a negative fringe motion. Any motion of the grooves to the right in Figure 1 produces a positive fringe motion at L and a negative fringe motion at R. Thus, these fringe motions due to specimen rigid body translation cancel out in eq. (1). The same averaging-out process is true for a rotation of AB about a line per-

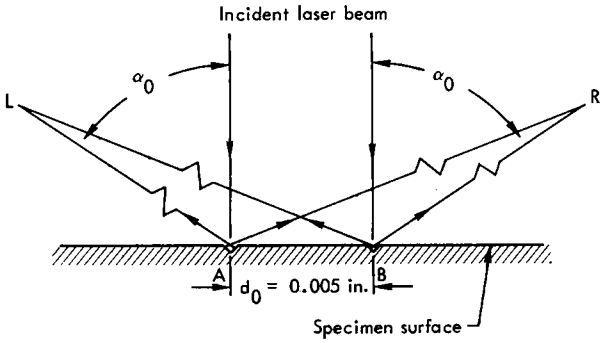

Fig. 1 Schematic of interferometric strain measurements over a short gauge length.

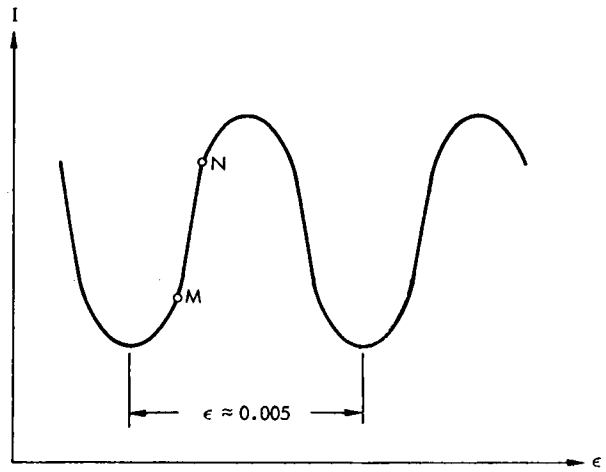

Fig. 2. Schematic of intensity variation with strain.

pendicular to the plane of the paper and passing through the midpoint of AB in Figure 1, However, other rigid body motion, such as that perpendicular to the specimen surface. cannot be removed by averaging and must be controlled or measured. In many static or dynamic material-response determination experiments, this other rigid body motion is sufficiently controlled.[2]

The intensity of the fringe pattern varies with angle according to a cosine-squared function modulated by the variation due to diffraction from the sides of the grooves.[1] This variation with angle is the same as the variation with strain as the fringes sweep past the observation positions L and R in Figure 1. Intensity variation with strain is illustrated in Figure 2. For a typical experimental setup, using $d_0 = 0.005$ in., $\lambda = 6328$ Å (He-Ne laser), and $\alpha_0 = 70°$, one complete fringe shift corresponds to a strain of 0.0054. This technique can be used to measure large strain by recording the passage of bright and dark fringes past the observation positions. Note that the absolute value of the intensity is not needed here, only the relative variation indicating the passage of fringes. For small strain, there is a substantial linear region (MN in Fig. 2) of the intensity curve that can be related to strain through proper calculation.[3] In this case of using common continuous-wave He-Ne lasers, the sensitivity of the technique is 4 microstrain, with a range of 1350 microstrain.

The experimental setup requires a laser operating in the TEM_{00} mode. He-Ne lasers in the 5–15 mW range have proved very satisfactory. (A 1-mW laser has also proven acceptable on some metals, providing an appropriate focusing lens is used.) Fringe motion is most easily recorded electronically using a photomultiplier tube masked with a slit that is narrower than the fringe spacing at the tube. The intensity–time variation may be recorded on an oscilloscope or chart recorder.

APPLICATION TO PLASTICS

The problem in applying this technique to plastics is the application of grooves that have suitable reflecting surfaces. Whereas grooves can be easily ruled onto polished metal samples with a diamond, the same is not true for plastics. Although grooves can be ruled on plastics, the plastics absorb a considerable amount of visible radiation, thereby producing a very dim fringe pattern. One method to improve the reflectivity is to coat the plastic with some type of metal into which grooves can be ruled.

Poly(methyl Methacrylate) (PMMA)

Grooves ruled directly onto PMMA have sufficient reflectivity to produce acceptable fringe patterns. A thin (~1000 Å) aluminum coating can also be vapor plated onto the PMMA before ruling; this impoves the fidelity of the patterns. Six samples with grooves ruled directly and six with grooves ruled on the vapor-plated coating were tested dynamically in a split Hopkinson pressure bar arrangement.[4] Typical traces using an uncoated specimen are shown in Figure 3. The smaller variations on the traces arise because of friction effects at the specimen–pressure bar interfaces. Figure 4 shows the reduced strain–time curve obtained from the traces in Figure 3. The data reduction involves plotting the time at which maximum and minimum occur and averaging them according to eq. (1).

Figure 5 compares the average strain–time curve for the uncoated samples with the average curve for the coated samples. The presence of the very thin vapor plating does not reinforce the sample or otherwise adversely affect the results.

Other Plastics and Plastic-Type Materials

The adaptability of the technique to materials other than PMMA was also examined. The technique of first vapor plating and then ruling the grooves gave acceptable fringe patterns on both polystyrene and poly(vinylchloride). However, this method did not

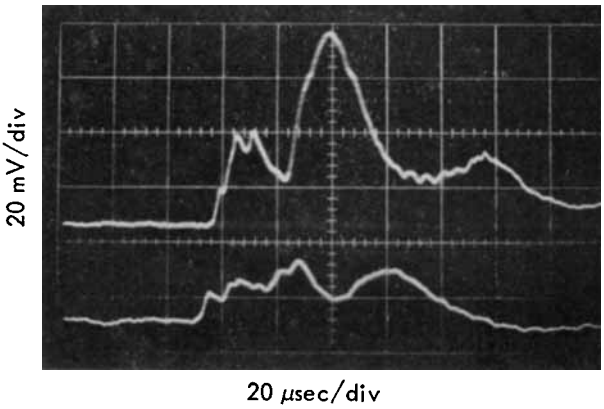

Fig. 3. Photograph of typical trace for dynamic strain measurement on uncoated PMMA.

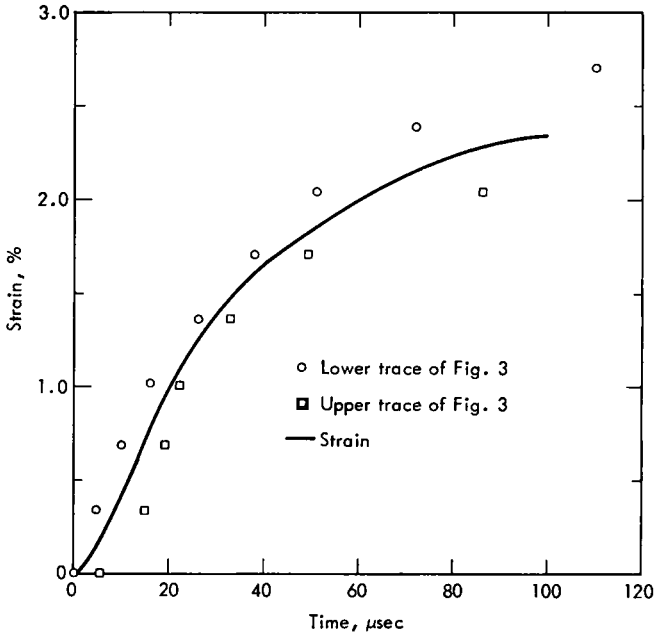

Fig. 4. Strain–time curve obtained from Fig. 3.

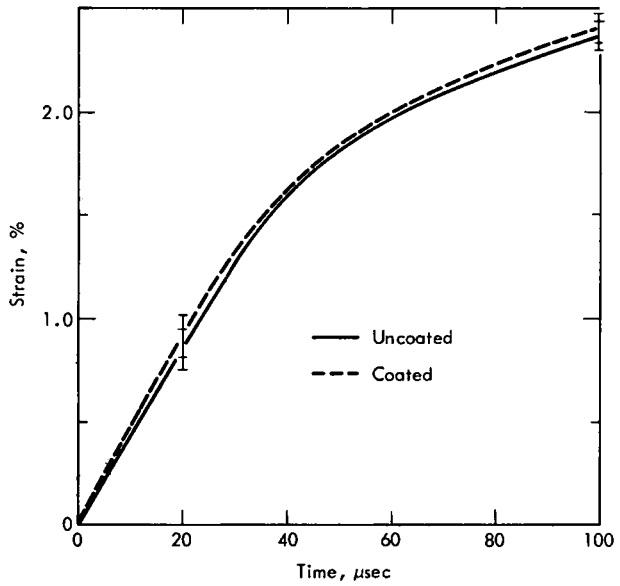

Fig. 5. Comparison of the average strain–time curves for uncoated and coated PMMA samples. Each curve represents six tests, and the vertical lines show the standard deviations.

give satisfactory results on four materials that mock the mechanical behavior of various high explosives (HE), and a different approach was required for application of the ISG technique.

These nonexplosive equivalents for HE all have grainy textures. The composition of the mock HE studied in most detail is 70.5 wt-% cyanuric acid, 14.5 wt-% $Ba(NO_3)_2$, and 15.0 wt-% Viton A (a du Pont Co. fluorocarbon rubber). Its density is 0.0675 lb/in.^{3}; the compositions and densities of the other three materials are generally similar.

First, a thin (~0.0015 in.) coating of Copon epoxy (epichlorhydrin bisphenol A-type epoxy with amine cure, manufactured by Boysen Paint Co.) with activator is applied to a small area on the smooth lateral surface of the specimen. A layer (~1500 Å) of aluminum is then vapor deposited over the very smooth curve epoxy surface, and the grooves are ruled.

Results are shown in Figure 6 for the mock HE described above. The conditions of

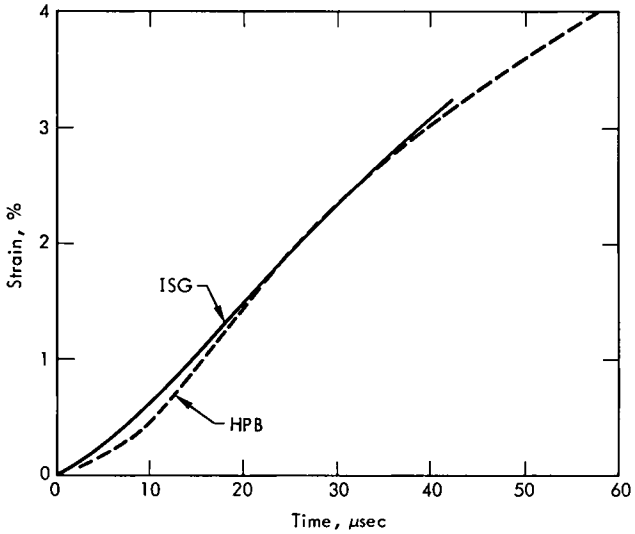

Fig. 6. Strain–time curve for mock HE specimen: length, 0.2065 in.; diam., 0.4995 in.; projectile velocity, 257 in./sec.

the test are given in the figure caption. The agreement between the ISG and the (independent) split Hopkinson pressure bar (HPB) reduced data[4] is extremely good and probably fortuitous, although repeat tests gave essentially the same results. The agreement indicates that the epoxy coating of the thickness used has negligible stiffening effect upon the specimen within experimental uncertainties of the ISG and HPB techniques.

It appears that the method described above would allow the ISG technique to be applied to a variety of plastic specimen materials, providing a satisfactory sample surface preparation and bond between the epoxy and the sample are obtained. Caution must be exercised in the use of such a method, however, because of the possible specimen reinforcement difficulties (see comments of a similar nature in the introduction with respect to strain gauges). A thinner epoxy coating could be applied if necessary. Finally, it should be noted that the materials to be studied should not be inhomogeneous on too large a scale, or else the short gauge-length ISG technique may not provide valid results.

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