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Strain Disturbances due to Viscoelastic Crack Propagation

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Synopsis

Local strain disturbances near a running crack in a viscoelastic material were investigated in PMMA. Specimens having different initiation crack tip radii and under different tensile strain rates were examined by use of a series of strain gauges placed parallel and close to the expected crack path, and by velocity gauges. The strain disturbance, which was observed ahead of the running crack front, diminished gradually owing to the viscoelastic damping. The maximum strain disturbances increased with increase in gross breaking load.

INTRODUCTION

Local strain disturbances near a running crack due to the dynamic crack propagation in viscoelastic solids such as poly(methyl methacrylate) (PMMA) are of interest. To analyze theoretically such strain disturbances near a running crack is difficult, even for the elastic case,[1] and, of course, much more difficult for the viscoelastic case. In the present report, an experimental approach was used in which the strain near a running crack was measured by use of strain gauges before and after the crack propagation. Several instrumentation procedures were used in combination with the velocity gauges for verification of a running crack front position.

EXPERIMENTAL

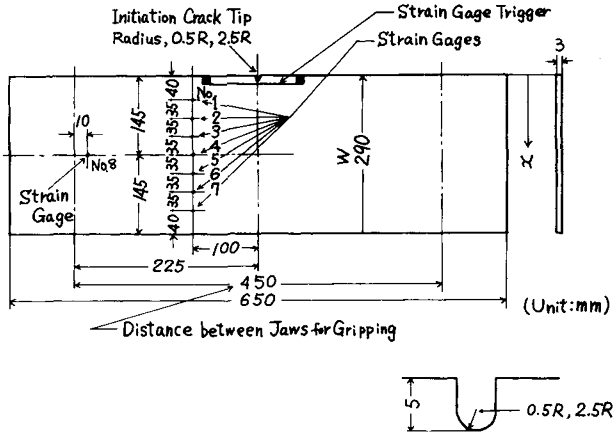
A conventional Instron-type tensile tester, UTM-1, manufactured by Toyo-Baldwin, Japan, was used for constant strain rate loading. The load was measured by a load cell.

PMMA specimens, as shown in Figure 1A, were prepared from Sumipex virgin sheet manufactured by Sumitomo Chemical Co., Ltd., Japan. The initiation crack tip radii ρ were 0.5 mm and 2.5 mm.

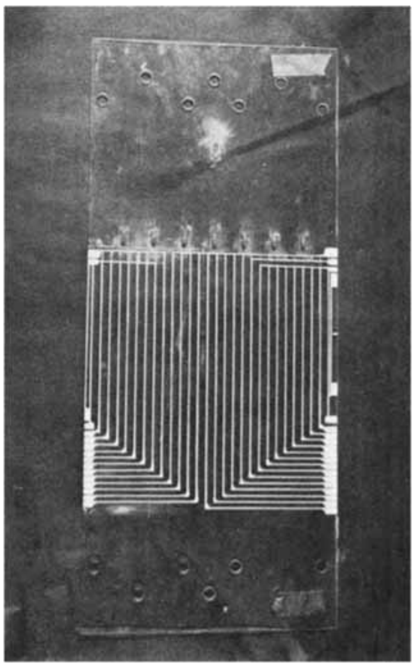
The strain measurement was done in two stages according to the response characteristics of the measuring instruments, as shown in Table I. At the beginning of loading until the crack initiation, conventional measuring instruments such as an electromagnetic oscillograph and associated amplifiers in combination with the strain gauges of the usual type were used.

TABLE I
Measuring Instrumentation

Stage	Measured for	Strain gauge	Amplifier	Recorder
I	From the beginning of loading until the crack initiation	KFC-2-Cl-11 (120 ohms), gauge length = 2 mm manufactured by Kyowa Electronic Instruments Co., Ltd., Japan	DM-6E and DM-6J manufactured by Kyowa Electronic Instruments Co. Ltd., Japan	Electromagnetic oscillograph "Photocorder" EMO-1, manufactured by Yokogawa Electric Works Ltd., Japan
II	After crack initiation	KFC-2-500-Cl-11 (500 ohms), gauge length = 2 mm, manufactured by Kyowa Electronic Instruments Co. Ltd., Japan	8 amplifiers manufactured by the authors' laboratory	2 dual-beam oscilloscopes DS-5305Bs, manufactured by Iwatsu Electric Co., Ltd., Japan



(A)



(B)

Fig. 1. PMMA specimen: (A) dimensions and strain gauge locations; (B) conductive coating wire arrangement.

Since a quick response capability is required after initiation of crack, another set of instruments, such as dual-beam oscilloscopes with the amplifiers specially manufactured by the authors' laboratory were used, as also shown in Table I. These instruments were triggered by breakthrough of conductive coating wire, du Pont No. 4817, denoted as a strain gauge trigger in Figure 1A. The strain gauges were placed on both surfaces, of a specimen at the same locations like a sandwich, so that one kind of strain gauge was placed on one side and another kind on the other side.

The running crack front position was verified by the velocity gauges. That is, the conductive coating wire, du Pont No. 4817, was fixed as shown in Figure 1B. Upon breakthrough of these coating wires by the passage of a crack, an electric signal is recorded on a Memoriscope, MS-5507, manufactured by Iwatsu Electric Co. Ltd., Japan, and thereby the position of the running crack front can be verified.

EXPERIMENTAL RESULTS AND DISCUSSION

Experimental conditions are as shown in Table II, in which the strain rate $\dot{\epsilon}$ is computed from $\dot{\epsilon} = V/L_0$, where V = cross-head speed and L_0 = the distance between jaws for gripping = 450 mm. The test temperature was 28°C. Two kinds of strain rates and also two kinds of initiation crack tip radii were employed in order to obtain different gross breaking loads.

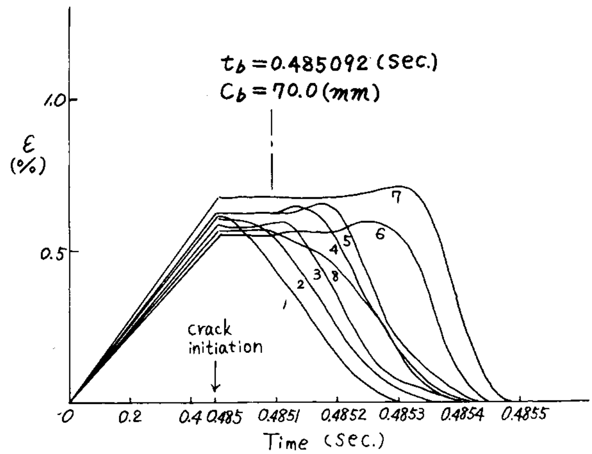


Fig. 2. Measured strains ϵ vs. duration of load ($\dot{\epsilon}$ = 1.85 × 10^{-2}/sec, ρ = 0.5 mm).

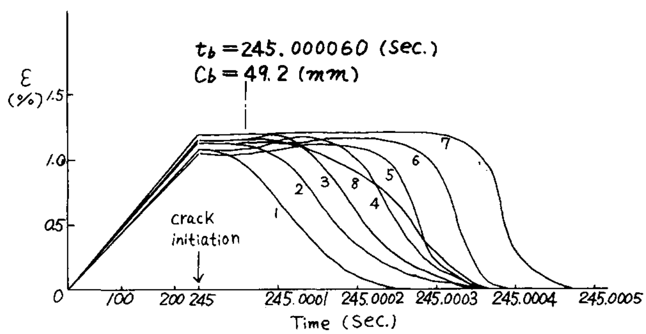


Fig. 3. Measured strains ϵ vs. duration of load ($\dot{\epsilon}$ = 7.4 × 10^{-5}/sec, ρ = 0.5 mm).

TABLE II
Experimental Conditions

Strain rate $\dot{\epsilon}$, sec^{-1}	Initiation crack tip radius mm	Number of speci-men	Average gross breaking load, kg	Refer to
1.85×10^{-2}	0.5	4	1831	Figures 2 and 5
7.4×10^{-5}	0.5	4	2797	Figures 3 and 6
1.85×10^{-2}	2.5	3	3959	Figures 4 and 7

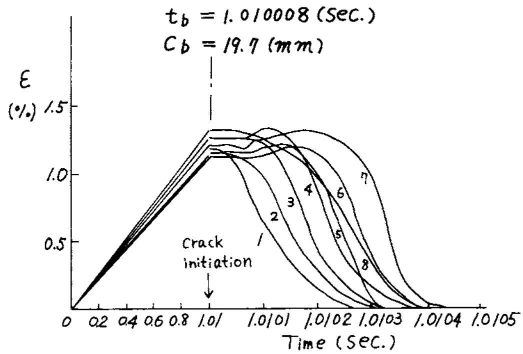


Fig. 4. Measured strains ϵ vs. duration of load ($\dot{\epsilon}$ = 1.85×10^{-2}/sec, ρ = 2.5 mm).

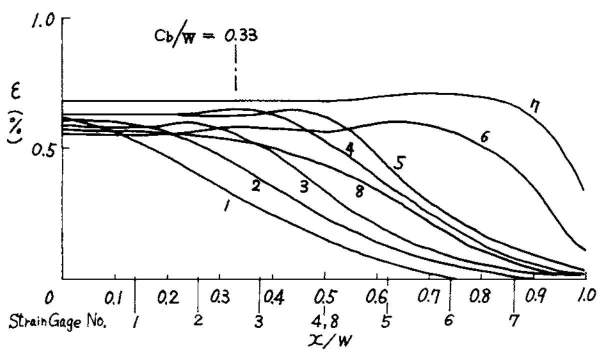


Fig. 5. Measured strains ϵ based on the running crack front x/W ($\dot{\epsilon}$ = 1.85×10^{-2}/sec, ρ = 0.5 mm).

Typical experimental results on strain ϵ and time elapsed after loading are shown in Figures 2 to 4, in which t_b = time until crack bifurcation and C_b = main crack length up to bifurcation. Note that the time scale is altered after crack initiation. The individual strain gauge number is denoted by a figure near the corresponding curve. The gradients in the strain–time relation until crack initiation are nearly equal to those computed from $\dot{\epsilon} = V/L_0$ in all cases. In Figures 2 to 4, though the strains are measured 100 mm apart, the expected crack passage for Nos. 1 to 7 strain

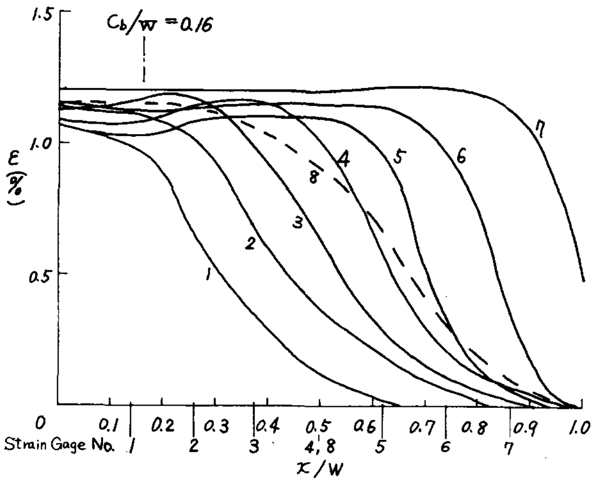


Fig. 6. Measured strains ε based on the running crack front x/W ($\dot{\epsilon}$ = 7.4 × 10^{-5}/sec, ρ = 0.5 mm).

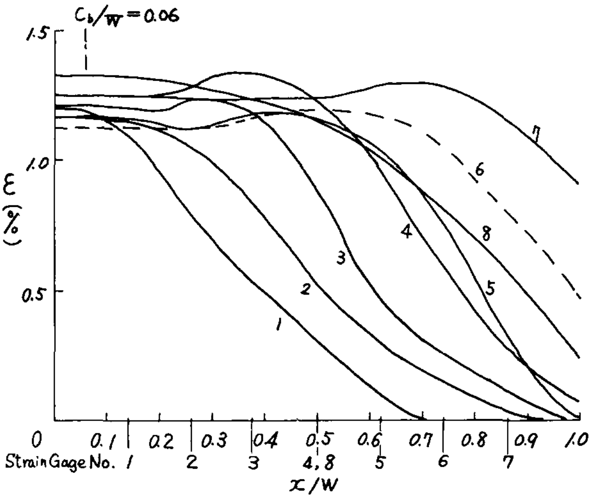


Fig. 7. Measured strains ε based on the running crack front x/W ($\dot{\epsilon}$ = 1.85 × 10^{-2}/sec, ρ = 2.5 mm).

gauges, and 215 mm apart for the No. 8 strain gauge, it is observed that the individual strain decreases with time elapsed after crack initiation. The larger strains are obtained for the larger breaking loads. Wavy patterns are observed for all strain gauges except for Nos. 1 and 2.

In order to correlate the measured strains with the propagating crack front positions, another diagrams will be shown. Figures 5 to 7 show the strain variation ϵ based on the running crack front position x/W, in which the positions of strain gauges are denoted on the abscissa and W is the width of a specimen. In these figures, it is noteworthy that the strain disturbance due to a running crack propagates several distance ahead of a running crack front, originating at x/W = approx. 0.2, as observed by the No. 3 strain gauge reading and diminishing gradually hereafter after reaching a maximum. Probably the elastic disturbance caused by a running crack front is greatest at about $x/W = 0.2$, and keeps going ahead of the running crack for a while, until it gradually diminishes and fades out owing to the viscoelastic damping. The waviness of strain disturbances increases with the gross breaking load.

CONCLUSIONS

The local strain disturbances due to a running crack were observed by use of strain gauges. It was found that these strain disturbances propagate ahead of the running crack front with their maximum occurring at about 20% of the specimen width after crack initiation. The strain grows and then diminishes gradually due to viscoelastic damping. The maximum strain disturbances increased with increase in gross breaking loads.

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References

1. K. B. Broberg, *Arkiv Fysik*, **18**, 159 (1960).

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