# Instantaneous Crack Resistance during Crack Propagation in a Viscoelastic Solid

AKIRA KOBAYASHI and NOBUO OHTANI, *Institute of Space and Aeronautical Science, University of Tokyo, Komaba, Meguro-ku, Tokyo, 153, Japan*

## Synopsis

Instantaneous crack resistance values during the mode I stable crack propagation in poly(methyl methacrylate) (PMMA) were investigated with the aid of the sector area method at different test temperatures. The crack resistance during stable crack propagation is a gradually decreasing function of crack passage at all temperatures. The rate decreases as the test temperature decreases, down to −30°C, irrespective of high initial crack resistance. The crack propagation velocity profiles, obtained through velocity gages, also show the decreasing function of crack passage. Both crack resistance $R$ and its gradient with respect to the crack propagation velocity, $dR/d\dot{C}$, become greater as the temperature decreases. $R$ becomes greater as $\dot{C}$ increases, contrary to the usual crack resistance behavior in metals.

## INTRODUCTION

The instantaneous crack resistance during stable crack propagation at various temperatures is of interest. Several techniques depicting the crack resistance in solids are: (1) the modified Griffith theory expressed in terms of fracture surface free energy, (2) fracture mechanics employing the critical stress intensity factors $K_c$ or the critical strain energy release rate $G_c$, and (3) measuring the specific work of fracture, e.g., fracture toughness or crack resistance $R$. The sector area method of category (3) proposed by Gurney and Hunt[1] for the viscoelastic case is quite suitable because it gives various crack resistance values in a single test, so that the rate dependence may be determined.

In the present paper, the instantaneous crack resistance during stable crack propagation at various temperatures in a viscoelastic solid (such as PMMA) is experimentally measured using the sector area method combined with velocity gage techniques.[2]

## EXPERIMENTAL

### Test Specimen and Experimental Techniques

To determine crack resistance values "$R$", load and deformation were recorded as the crack advances. A stiff testing apparatus and test specimen geometry were required to stabilize crack propagation.

The PMMA specimen (Fig. 1), made from Sumipex virgin sheet manufactured by Sumitomo Chemical Co. Ltd., Japan, is of compact tension geometry, in which the milled crack starter slots are fatigued to a length of 4 mm included in $C_0$ = 33 mm, to achieve stable crack propagation. During the crack propagation,

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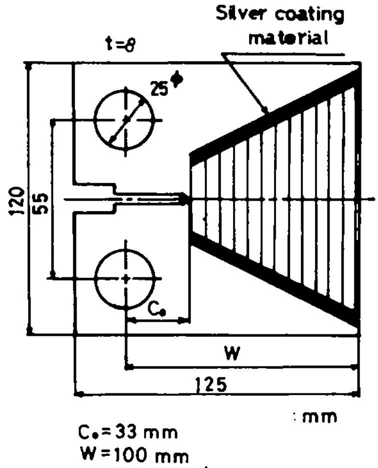



Fig. 1. PMMA specimen with velocity gages.

velocity $\dot{C}$ was measured using velocity gages consisting of a series of conducting wires du Pont No. 4817 conductive silver-coated material, placed at intervals on the expected path of the crack and perpendicular to the direction of crack propagation, as shown in Figure 1. Thus, the Instron-type tensile tester was employed to perform the monotonically loaded cracking experiment in mode I on the specimen.

The test temperatures were −30°C (liquid nitrogen), 12–15°C (room temperature), and 52–55°C (hot air). The relative displacement at the loading position was measured by clip gages, and the load, by a load cell.

The associated measuring block diagram is shown in Figure 2.

## EXPERIMENTAL RESULTS AND DISCUSSION

During the experiment of stable crack propagation under the constant crosshead speed of 0.5 mm/min, the load $P$ and the specimen opening displacement between loading pins $\delta$ were measured to estimate the crack resistance $R$ by the sector area method (Fig. 3). The $R$ values representing each triangle are estimated by dividing the area of each triangle by the increment in crack area (Fig. 3). Crack resistance curves, as a function of a running crack front at various temperatures, are shown in Figures 4–6. These $R$ curves (Figs. 4–6) are further shown together in Figure 7 for comparison. Judging from these figures, it is observed that (1) $R$ is a decreasing function of crack length $C$ irrespective of test

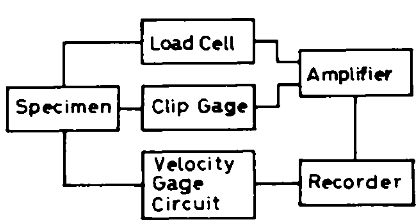
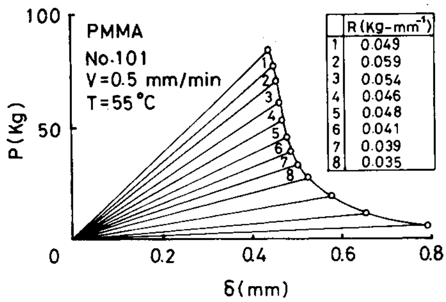



Fig. 2. Measuring block diagram.




| | R (Kg-mm⁻¹) |
|---|---|
| 1 | 0.049 |
| 2 | 0.059 |
| 3 | 0.054 |
| 4 | 0.046 |
| 5 | 0.048 |
| 6 | 0.041 |
| 7 | 0.039 |
| 8 | 0.035 |

Fig. 3. Load $P$ vs. displacement $\delta$. Crack resistance $R$ is estimated by dividing the area of each triangle by the increment in crack area.

temperature, (2) $dR/dC$ becomes steeper as the temperature $T$ decreases, and (3) a higher initial $R$ value is obtained as $T$ decreases.

Crack velocity during stable crack propagation, $\dot{C}$, for individual test temperatures, is shown in Figure 8 as a function of a running crack front. All $\dot{C}$ curves show the decreasing function of crack length, and $\dot{C}$ for −30°C is always lower than the other two test temperature cases, while those for $T$ = 12–15°C and $T$ = 52–55°C behave in like fashion (Fig. 8). All $\dot{C}$ curves are decreasing as $C/W$ values increase, where $W$ = 100 mm (Fig. 1). This is the case when employing compact tension-type specimens.

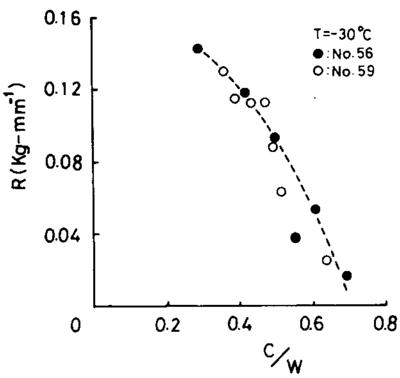



Fig. 4. Crack resistance $R$ as function of a running crack front $C/W$ at −30°C.

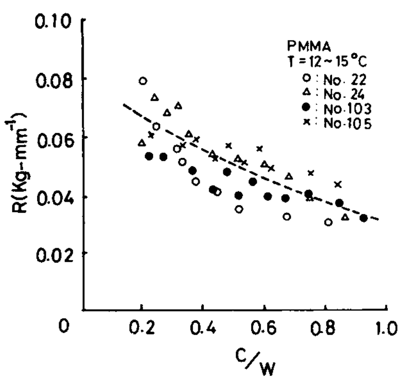



Fig. 5. Crack resistance $R$ as function of a running crack front $C/W$ at 12–15°C.

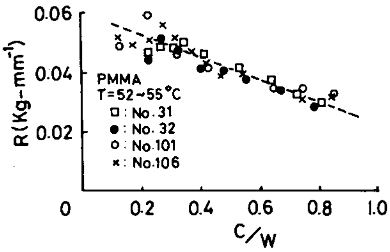



Fig. 6. Crack resistance $R$ as function of running crack front $C/W$ at 52–55°C.

Figure 9 shows the correlation between $\dot{C}$ and $R$ for various test temperatures. Both $R$ and $dR/d\dot{C}$ become greater with a decrease in test temperature. The individual $R$ values increase with an increase in $\dot{C}$, contrary to the usual crack resistance tendency in metals. This crack resistance behavior agrees with results obtained by Atkins et al.[3].

## CONCLUSIONS

Instantaneous crack resistance during stable crack propagation in a viscoelastic solid (such as PMMA) was estimated by the sector area method at different test temperatures. Compact tension specimens with velocity gages were subjected

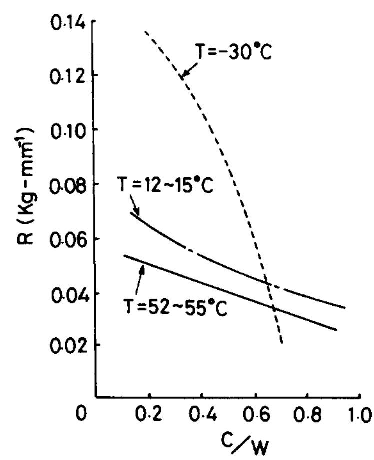



Fig. 7. Comparison of crack resistance $R$.

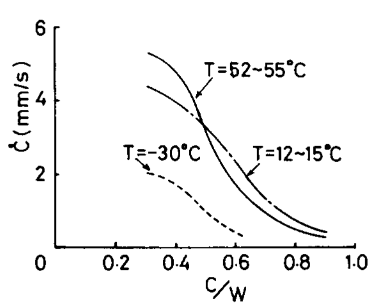



Fig. 8. Crack propagation velocity $\dot{C}$ at individual test temperatures as function of a running crack front $C/W$.

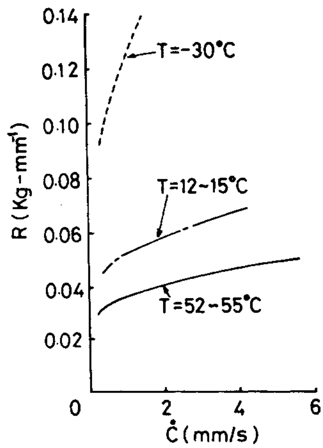



Fig. 9. Crack resistance $R$ vs. crack propagation velocity $\dot{C}$ at −30, 12–15, and 52–55°C, respectively.

to mode I tension loading at slow cross-head speed. Stable crack propagation was realized to estimate crack resistance values at −30, 12–15, and 52–55°C, respectively.

Crack resistance $R$ is always a decreasing function of a running crack front $C$, irrespective of test temperature. $dR/dC$ becomes greater as the temperature decreases, and high initial $R$ values are obtained as the temperature decreases. All crack propagation velocities $\dot{C}$ are decreasing functions of $C$. The $\dot{C}$ values for 12–15°C and 52–55°C yield similar curves, while for −30°C, $\dot{C}$ is less than half the value of those for 12–15°C and 52–55°C.

As for the $R$–$\dot{C}$ relation, both $R$ and $dR/d\dot{C}$ become greater as the temperature decreases. Individual $R$ becomes greater as $\dot{C}$ increases. These results are contrary to the usual crack resistance behavior of metals.

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