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Initial Slow Crack Growth Behavior Followed by Rapid Brittle Fracture in a Viscoelastic Solid

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Synopsis

Initial dynamic crack propagation behavior in a viscoelastic solid just after crack initiation was investigated by newly devised instrumentation at different temperatures. It was observed that initial slow crack growth precedes rapid brittle fracture. The very initial slow crack growth first appears as ductile fracture and successively as brittle crack propagation, and the latter only exists within very short crack passage. It is also recognized that this slow crack growth in a brittle manner greatly depends on the temperature.

INTRODUCTION

The investigations on viscoelastic dynamic crack propagation, so far, have mainly stressed either terminal crack velocity or steady-state crack velocity, and the initial transient crack propagation behavior just after a running crack initiation appears to have remained unexplored.

In the present report, the very initial transient crack propagation in a viscoelastic solid is studied by newly devised instrumentation which makes measurement of the transient rapid event easier, at different temperatures. The following will describe the details of this procedure.

EXPERIMENTAL

Modified Velocity Gauge Technique

As is well known, there are several techniques for measuring crack propagation velocity: the impedance method, the ultrasonic method, the high-speed photography method, and the velocity gauge method.[1] Among these methods, velocity gauges have been used by the present authors for several years. Although the velocity gauge technique may be recommended, it is, however, unfavorable for continuous crack velocity measurements because of its intermittently deposited conductive wires painted on the specimen surface normal to the predicted running crack passage in advance of an initial notch.

Since the rapid change in dynamic crack propagation velocity might be well

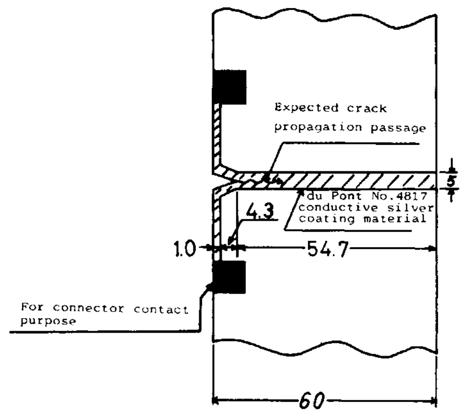

Fig. 1. Modified velocity gauge arrangement.

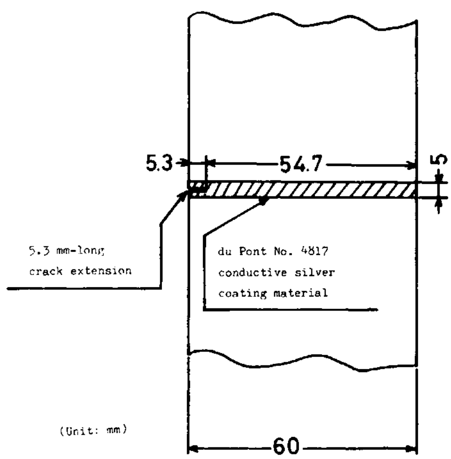

Fig. 2. Electrically equivalent modified velocity gauge configuration concept.

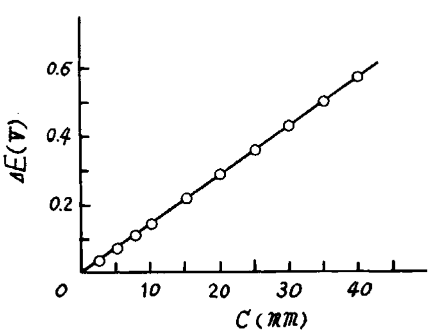

Fig. 3. Velocity gauge voltage variation output as a function of crack length.

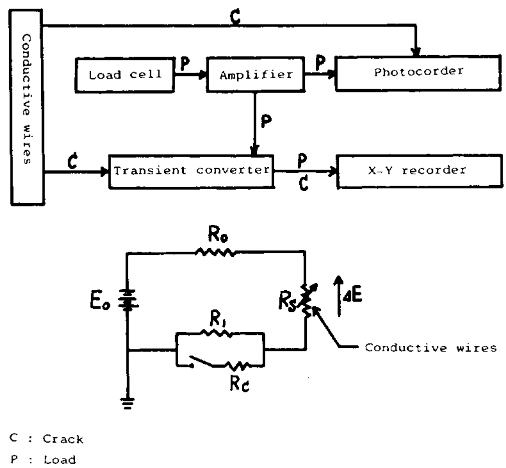

Fig. 4. Block diagram for measurement of crack propagation velocity and load.

expected during the initial transient crack propagation stage, such a conventional intermittently deposited velocity gauge method is not suited to follow the very rapid change in detail. The newly devised continuous crack propagation velocity measurement technique using velocity gauges should be developed and employed to measure the crack propagation velocity continuously from the initial crack propagation initiation. The newly devised instrumentation, termed modified velocity gauge technique, was developed and employed by the present authors.

The conductive materials are deposited in the manner as shown in Figure 1. The modified velocity gauge arrangement (Fig. 1) is such that the conductive material is uniformly painted to become electrically equivalent to 5.3-mm-long crack extension in the unnotched specimen as shown in Figure 2. In Figure 1, the conductive material for connector contact purpose, shown by the shaded regions, is painted with du Pont No. 4817 conductive silver coating material, while a mixture of 33 vol % No. 4817 coating material and 67 vol % n-butyl acetate is applied to the remainder in order to increase the specific resistance. In fact, the specific resistance in the latter is 50 times greater than that of the notched parts. Now the conductive silver coating material is deposited alongside the predicted

TABLE I
Measuring Instruments

Instrument	Type	Manufacturer
Photocorder	Electromagnetic oscillograph EMO-1	Yokogawa Electric Works, Ltd., Japan
Transient time converter	Analog-digital memoriscope TCED-1000 (sampling time, 0.1 microsec)	Riken Denshi Co., Ltd., Japan
X—Y Recorder	F-43P	Riken Denshi Co., Ltd., Japan
Amplifier	DM-6J	Kyowa Electronic Instruments Co., Ltd., Japan
Load cell		Toyo-Baldwin, Japan

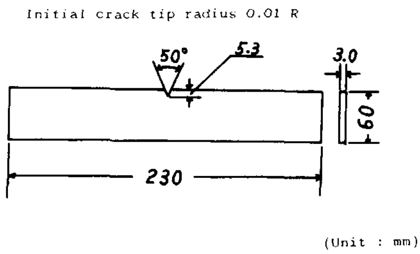

Fig. 5. Specimen configuration.

running crack propagation passage, producing a voltage variation as a function of crack length (Fig. 3) corresponding to the breakthrough of conductive material as the crack advances; thus, continuous crack propagation velocity measurement can be achieved. An associated measurement block diagram is presented in Figure 4 in which the slow crack propagation velocity is measured by a Photocorder and the rapid one, by a Transient Converter. The load also can be measured simultaneously as shown in Figure 4. The measuring instruments are listed in Table I.

Specimen

Poly(methyl methacrylate) (PMMA) specimens are prepared from virgin Sumipex sheet, a product of Sumitomo Chemical Company. The configuration is as shown in Figure 5. The initial crack tip radius is 0.01 mm; the initial crack length, 5.3 mm; and the distance between jaws for gripping, 100 mm.

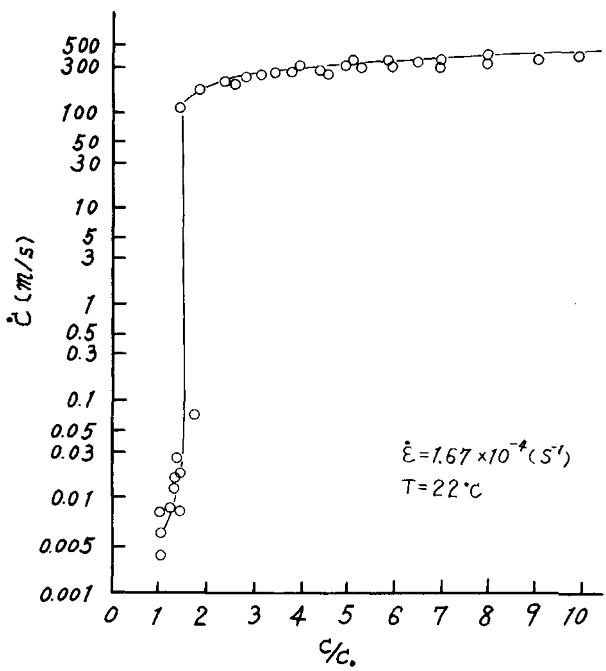

Fig. 6. Experimental results of crack propagation velocity $\dot{C}$ as a function of nondimensional crack length C/C_0 (22°C).

Loading Apparatus

An Instron-type tensile tester of Toyo-Baldwin make, UTM-1, was used to apply a constant cross-head speed of 1 mm/min to the specimen. The equivalent strain rate is 1.67×10^{-4}/sec.

Temperature Environment

The experiments were conducted at 22°C and 53°C. The hot air flow produced by a Braun dryer was used for the 53°C environment; the specimen was tested in this environment after steady-state conditions were achieved. The rate of air flow was small; consequently, no unfavorable effects on the test results were observed. Six specimens were tested at 22°C and seven, at 53°C.

EXPERIMENTAL RESULTS AND DISCUSSION

Owing to the newly devised instrumentation described thus far, the initial transient rapid events in dynamic crack propagation were successfully measured.

The dynamic crack propagation velocity $\dot{C}$ as a function of the nondimensional crack length C/C_0 is presented in Figure 6 for 22°C and in Figure 7 for 53°C, respectively. The stress during crack propagation σ versus the nondimensional crack length C/C_0 is shown in Figure 8 for 22°C and in Figure 9 for 53°C. These stresses are obtained from the corresponding loads divided by the minimum sectional area of 164.1 mm^2. In view of these experimental data, both the stress

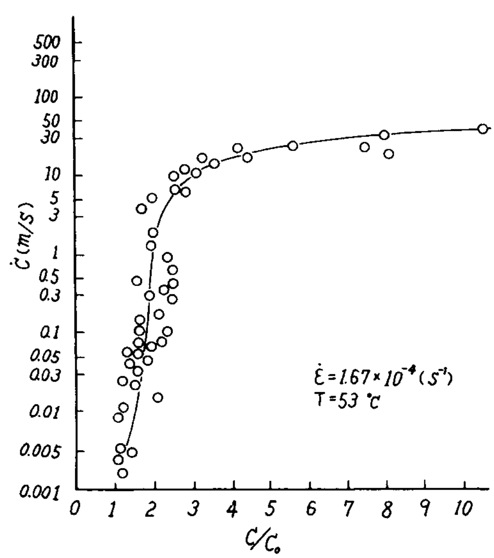

Fig. 7. Experimental results of crack propagation velocity $\dot{C}$ as a function of nondimensional crack length C/C_0 (53°C).

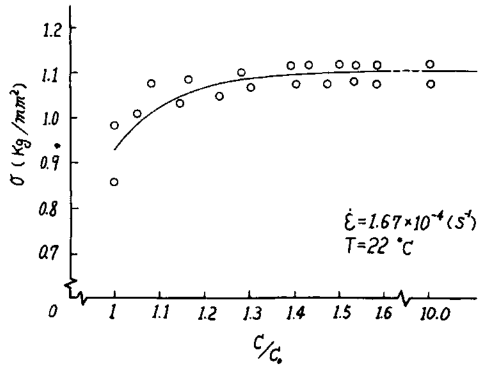

Fig. 8. Experimental results of stress during crack propagation as a function of nondimensional crack length C/C_0 (22°C).

during crack propagation and the dynamic crack propagation velocity are lower at 53°C compared with those obtained at 22°C. As a matter of course, those obtained above are well consistent with the previous results reported by the present authors.[2]

The initial transient slow crack growth behavior is more conspicuous at 53°C. The stress begins to maintain a constant value of σ = 1.1 kg/mm^2 at C/C_0 = 1.5 for 22°C, while the stress reaches a constant of 0.74 kg/mm^2 at C/C_0 = 1.2 for 53°C, as the stress variation during the crack propagation exhibits (Figs. 8 and 9). In principle, ductile crack propagation requires an increase in applied stress; however, the crack propagates without any increase in applied stress for brittle fracture. In this respect, both for 22°C and 53°C, there exist several stress increases just after the running crack initiation, which is essentially ductile fracture. The experimental results show that the viscoelastic materials, such as PMMA, require the ductile fracture just after the initial running crack initiation followed

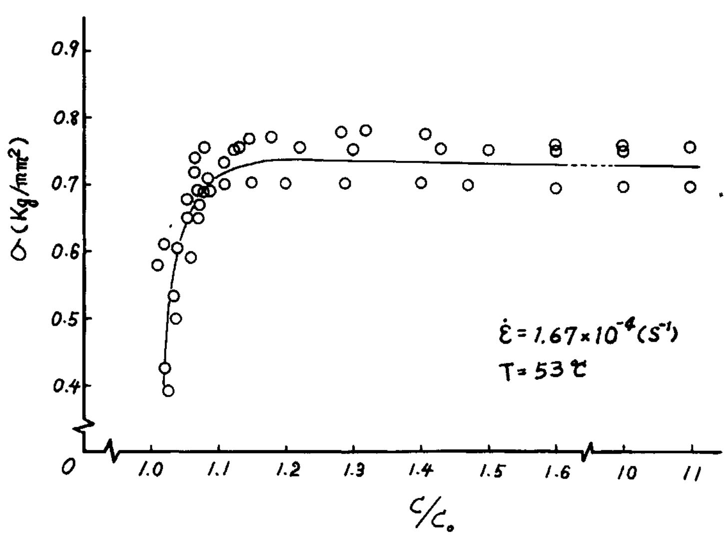

Fig. 9. Experimental results of stress during crack propagation as a function of nondimensional crack length C/C_0 (53°C).

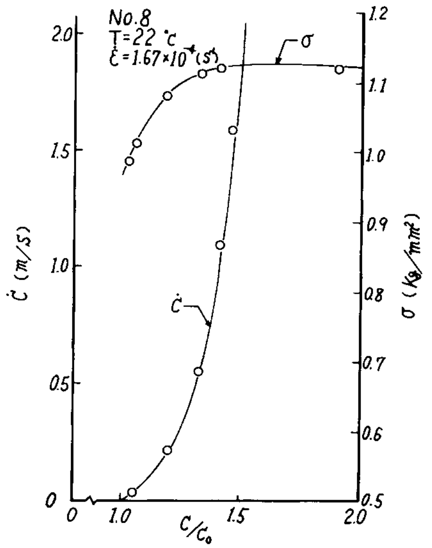

Fig. 10. Initial slow crack growth behavior compared with breaking stress (22°C).

by rapid brittle fracture; in contrast, during the elastic crack propagation, the breaking stress criterion is of constant value throughout the whole crack propagation, including the very initial transient crack propagation.

Further details of initial slow crack growth behavior are shown in Figures 10 and 11, which describe the correlation between the initial slow crack growth rate $\dot{C}$ and the breaking stress variation in terms of nondimensional crack length C/C_0, at 22°C and at 53°C, respectively. These are typical experimental data, and similar tendencies are observed for other specimens. The stress during crack propagation at 53°C is, of course, lowered due to strength degradation caused

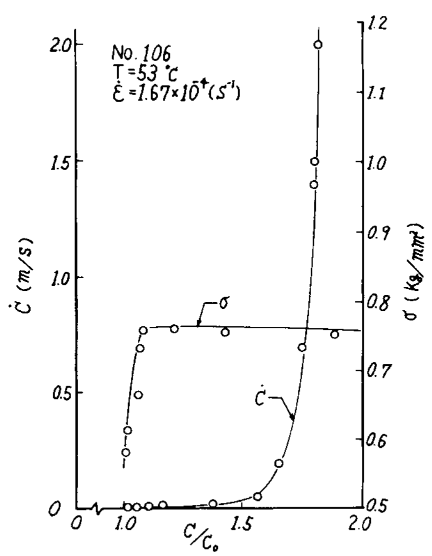

Fig. 11. Initial slow crack growth behavior compared with breaking stress (53°C).

by heating. However, it is noteworthy that the ductile fracture zone, with increasing stress region at 53°C, is shorter than that of the 22°C environment. That is, the crack propagation initiates from any stress raiser, such as an initial crack, as the applied stress increases; and the catastrophic brittle fracture of constant stress is envisaged in shorter crack passage after crack initiation in the case of 53°C environment, although the running crack propagation velocity is very slow, as shown in Figure 11. Therefore, from the viewpoint of breaking stress value, the initial slow crack growth behavior (e.g., assuming $\dot{C} < 0.5$ m/sec) at 53°C consists of both ductile and brittle fracture, while only the ductile fracture with increasing stress region exists for the 22°C case as seen in Figure 10.

CONCLUSIONS

Initial transient crack propagation in a viscoelastic solid just after crack initiation was investigated by newly devised instrumentation of modified velocity gauge techniques. It was found that initial slow crack growth followed by rapid brittle fracture exists. This initial slow crack growth consists of ductile fracture at room temperature; however, it consists of both ductile and brittle fracture at 53°C.

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