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Prefatigue Hysteresis Effects on Viscoelastic Crack Propagation

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Synopsis

Prefatigue hysteresis effects on viscoelastic crack-propagation velocity were investigated through velocity-gauge techniques at different temperature levels. It was found that prefatigue effects accelerate elastic predominance in viscoelastic dynamic crack propagation, approaching elastic brittle fracture as shown by Berry's equation. This results in greater dynamic crack-propagation velocity at any given test temperature level.

INTRODUCTION

Viscoelastic dynamic crack propagation was studied by the present authors.[1,2,3] However, these studies were carried out under virgin material conditions and no prefatigue effects were investigated. It is already known that the fatigue effects make the material brittle as in the case of metals; therefore, such prefatigue effects might also be expected to make several contributions to the dynamic crack-propagation behavior in viscoelastic materials; the elastic predominance, caused by an increasing brittle condition, might surely be expected to have an influence on the viscoelastic dissipation properties governing the dynamic crack-propagation velocity. The present paper describes the prefatigue effects on viscoelastic dynamic crack propagation at different temperature levels.

EXPERIMENTAL

Specimen

Poly(methyl methacrylate) (PMMA) sheet, Sumipex, produced by Sumitomo Chemical Company, Japan, is used as the specimen material (lot number 107-641). The individual specimen configuration is shown in Figure 1, in which the starting notch is machined after prefatigue hysteresis.

Prefatigue Hysteresis

The prefatigue hysteresis (Table I) was achieved at room temperature (22°C) through the use of a servopulser, EHF-10, manufactured by Shimadzu Seisakusho, Ltd., Japan. In the preliminary test, the number of cycles to failure at 12 Hz = $1.3\times10^5 \sim 3.5\times10^5$ and the static breaking stress σ_b = 7 kg/mm^2 were obtained for unnotched specimens.

Dynamic Crack Propagation Measurements

The specimen shown in Figure 1 was subjected to constant cross-head speed tension of 2 mm/min (equivalent strain rate of 1.85×10^{-4}/sec) at 22° and 50°C, respectively, in an Instron tensile tester in order to initiate dynamic crack propagation from the starting notch. The relative humidity was 60 ~ 63%.

The breaking stress was measured by the load cell attached to the tensile tester.

The velocity-gauge technique[4] was used to obtain the dynamic crack propagation velocity. Velocity gauges consist of a series of conducting wires, du Pont No. 4817 conductive silver coating material, placed at certain intervals on the projected path of the crack and perpendicular to the direction of crack propagation, as shown in Figure 2. These wires form one leg of a bridge (Fig. 3) which

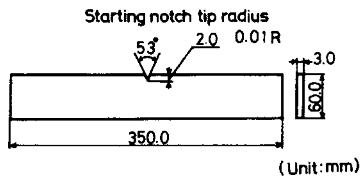

Fig. 1. Specimen dimensions.

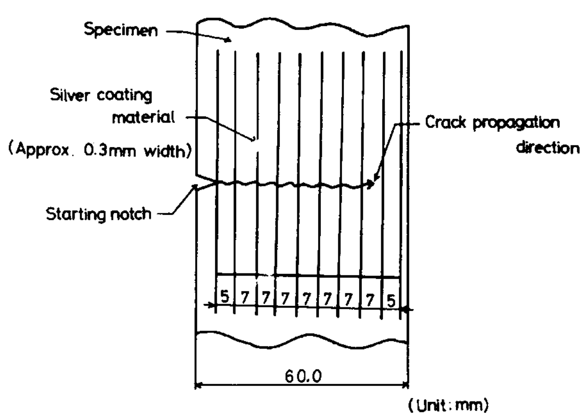

Fig. 2. Velocity-gauge arrangement.

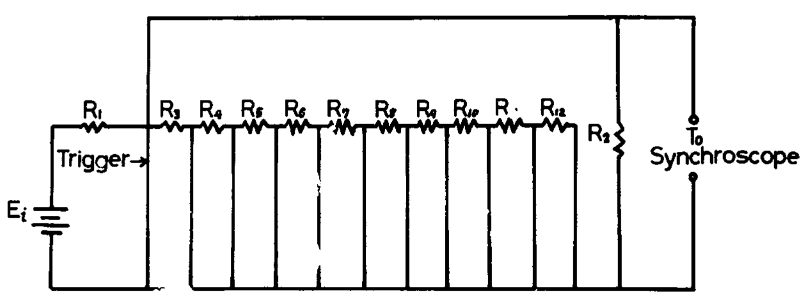

Fig. 3. Electronic circuit.

is connected to a Synchroscope DS-5305B, made by Iwatsu Electric Co., Ltd., Japan. The times at which these wires break, owing to the propagating crack, were obtained from the trace on the Synchroscope. Thus, the average crack-propagation velocity between wires can be obtained. The virgin specimens, which were free of prefatigue hysteresis, were also examined for comparison.

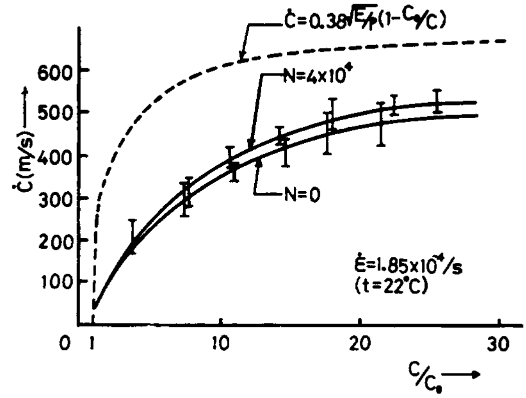

Fig. 4. Dynamic crack-propagation velocity profiles at 22°C.

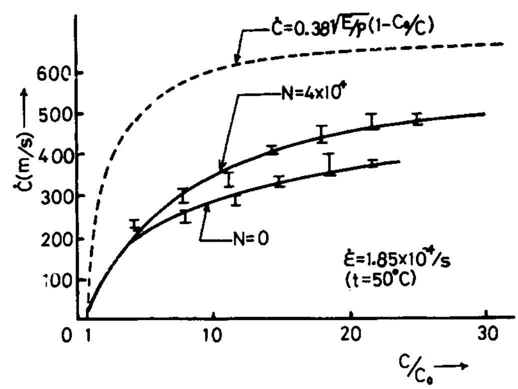

Fig. 5. Dynamic crack-propagation velocity profiles at 50°C.

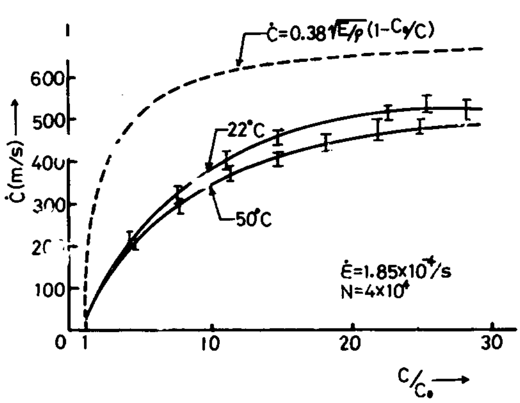

Fig. 6. Dynamic crack-propagation velocity profiles in the prefatigue hysteresis condition.

TABLE I
Prefatigue Hysteresis

Stress amplitude	Wave pattern	Prefatigue cycles
$0 \rightleftarrows 2.8$ kg/mm^2	sine (12 Hz)	4×10^4

TABLE II
Number of Specimens

Prefatigue hysteresis	22°C	50°C
4×10^4	4	2
0	3	3

RESULTS AND DISCUSSION

Experimental results on the dynamic crack-propagation velocity are shown in Figures 4–7, and those on the breaking stresses for notched specimens are shown in Figures 8 and 9. It is well known that Berry's equation[5] can be applied for the dynamic crack-propagation velocity in the brittle elastic solid with any starting notch tip radius. In Figures 4–7, Berry's equation is also plotted for comparison. Berry's equation is expressed as

$$\dot{C} = 0.38\sqrt{E/\rho}\,(1 - C_0/C)$$

for the lower boundary, where $\dot{C}$ is the dynamic crack-propagation velocity, E is Young's modulus, ρ is the density, C_0 is the starting notch length, and C is the arbitrary running crack length. Berry's curve is plotted with $E = 299$ kg/mm^2 and $\rho = 122.4$ kg.sec^2/m^4, obtained in the uniaxial tension creep test assuming a three-parameter model and the density measurement, respectively, at 22°C. Numbers of specimens are as shown in Table II.

The prefatigue hysteresis effects on the dynamic crack propagation velocity $\dot{C}$ in PMMA at 22°C and 50°C are shown in Figures 4 and 5, respectively. The dynamic crack-propagation velocity in the prefatigued condition is higher than in the virgin-state condition, irrespective of temperature, although several

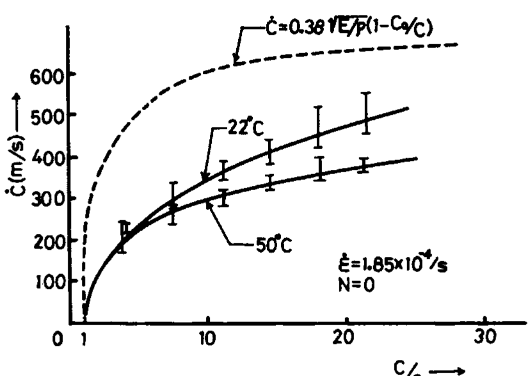

Fig. 7. Dynamic crack-propagation velocity profiles in the virgin-state condition.

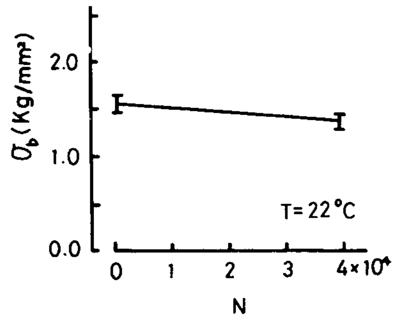

Fig. 8. Breaking stress vs number of prefatigue cycles at 22°C.

scatters are observed. Especially at 50°C, the distinct tendency dependent on the prefatigued condition can be recognized in the crack-propagation velocity. The fact may be explained on the basis that the material becomes brittle due to prefatigue hysteresis resulting in a decrease in viscoelasticity, thus enhancing the elastic characteristics and approaching Berry's equation. The prefatigue contribution may be recognized to be similar to the case of metals.

The effects of temperature on the dynamic crack-propagation velocity are shown in Figure 6 for the prefatigue hysteresis condition of 4×10^4 cycles and in Figure 7 for the virgin-state condition. It is recognized that the effects of temperature on the dynamic crack-propagation velocity are more pronounced in the virgin-state specimens than in the prefatigue hysteresis ones.

The prefatigue hysteresis effects on the breaking stresses are shown in Figure 8 for 22°C and in Figure 9 for 50°C. At 22°C, the breaking stresses are dependent on the prefatigue hysteresis, decreasing as the prefatigue hysteresis increases (Fig. 8). At 50°C, however, no prefatigue hysteresis contribution on the breaking stresses is observed (Fig. 9). The virgin specimen is distinctly affected by the temperature contribution on the breaking stress value.

CONCLUSIONS

Prefatigue hysteresis effects on viscoelastic crack-propagation velocity were investigated and compared with the virgin-state case by velocity-gauge techniques at different temperature levels. It was found that the dynamic crack-propagation velocity in the viscoelastic solid becomes greater at the prefatigued

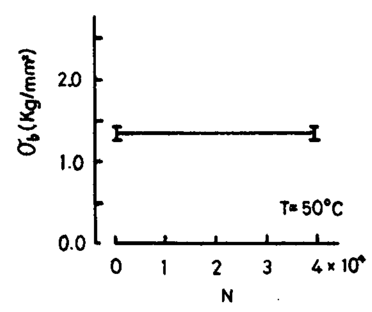

Fig. 9. Breaking stress vs number of prefatigue cycles at 50°C.

condition irrespective of test temperature, and that the dynamic crack-propagation velocity in the prefatigue hysteresis specimens approaches the theoretical in Berry's equation $\dot{C} = 0.38 \sqrt{E/\rho}\,(1 - C_0/C)$ for elastic brittle fracture.

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