WAVY CRACK PROPAGATION IN INTERNALLY PRESSURIZED GLASS TUBE

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ABSTRACT

It is well-known that when a high pressure gas tube fractures, a crack often propagates sinusoidally instead of running straight axially perpendicular to the hoop stress direction. In this study, fracture experiments were conducted using glass tubes by pressurizing internally with high pressure water and the paths of the crack propagations were observed. It has been clarified that a wavy crack often appears even in a brittle tube like glass pressurized internally by liquid (water) and that especially when the ratio of the thickness to the external diameter of a glass tube is very small, a wavy crack is likely to be running. As the results of the experiments with changing the size of glass tube, it has been clarified that the shapes of the wavy cracks are approximately similar to one another. Furthermore, the crack propagation was monitored by a high-speed video camera system and as the result, it has been shown that a crack snakes sinusoidally only when the crack propagation velocity is small comparing with the elastic wave velocity of glass and that the wavy crack never appears when the crack velocity is large. Therefore, it can be concluded that the mechanism of the wavy crack propagation is not due to the dynamic effect resulting from the rapid crack propagation.

1 INTRODUCTION

When a flat plate is subject to uniaxial tension, a crack will propagate straight perpendicular to the loading direction until branching. However, when the stress distribution becomes complicated, it is very difficult to predict the path of crack propagation and interesting crack patterns are often observed. For example, spiral cracks or crescent periodic cracks in drying precipitates (Néda et al. [1]) or coating films (Sendva et al. [2]), wavy cracks in a quenched brittle plate (Hirata [3], Yuse et al. [4], Ferney et al. [5], Deegan et al. [6]) and wavy cracks in an internally pressurized tube with gas (Shannon et al. [7], Williams et al. [8]) have been reported. In this study, wavy cracks in internally pressurized tubes are focused on and brittle glass tubes were used as the specimens. Each specimen was pressurized by high pressure water and a crack was initiated and propagated from a initial notch. Crack patterns were observed and the features of the wavy crack propagations were investigated.

2 EXPERIMENTATION

Figure 1 shows the schematic illustration of the experimental apparatus. This apparatus is composed of the holder sustaining a specimen, the hand pump pressurizing the specimen internally and the pressure gauge. As the specimens, glass tubes with the external diameter 10-45 mm, the length 200-400 mm and the thickness 1.2-3.2 mm were used. An initial notch is introduced in each specimen using a diamond cutter and the heat treatment (holding 570°C for 5 minutes before furnace cooling) was given in order to remove the residual stress. The specimen was covered with a thin vinyl film at the outer surface in order to avoid scattering of broken pieces and the initial notch was covered with a film internally in order to avoid the leakage of high pressure water. The specimen was fixed to the flanges of the holder. One of the flanges is connected to the hand pump by a pressure-resistant hose and the other side is to the pressure gauge. The holder was soaked in water with the specimen and the internal pressure was applied to the specimen by the hand pump in order to initiate a crack from the initial notch. The crack pattern was observed and the crack tip velocity was measured by a high-speed video camera system.

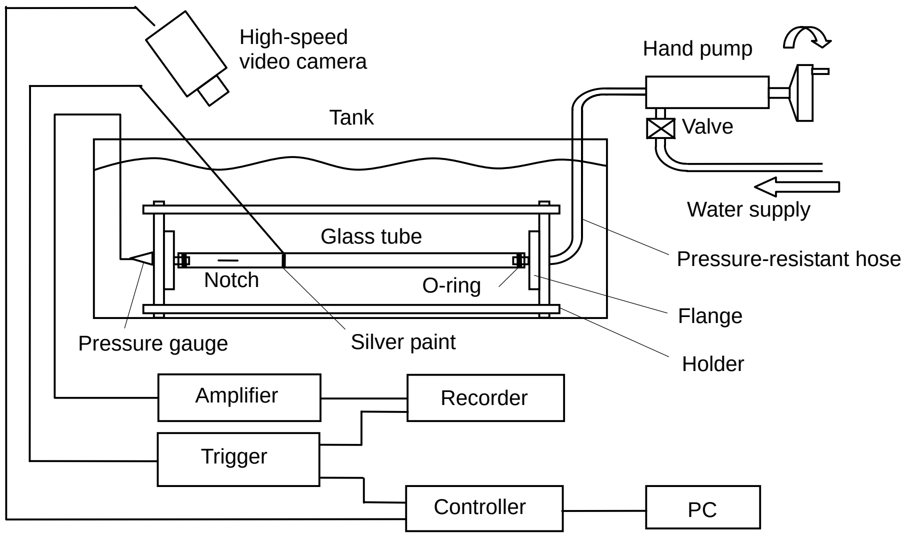


Figure 1: Schematic illustration of the experimental apparatus.

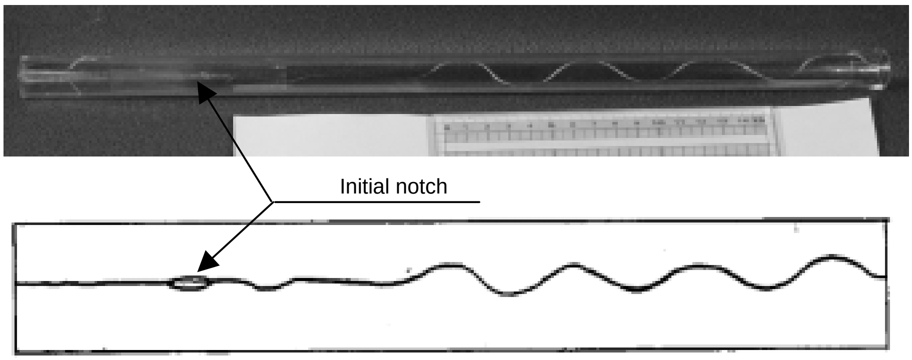


Figure 2: An example of the wavy crack propagation in an internally pressurized glass tube with the external diameter 18 mm, the length 400 mm and the thickness 1.2 mm. The photograph and its trace are shown. Internal pressure = 0.23 MPa.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 2 is an example of the typical crack path obtained in this experiment. In many cases, a crack snakes sinusoidally after propagating straight in the axial direction for a little distance. The distances of the straight crack propagation are various and there is almost no correlation between the distance of the straight crack propagation and the size of the specimen. In some cases, a crack propagates straight to the end of the specimen without snaking. The frequency at which the wavy crack appears was investigated with changing the ratio of the thickness to the external diameter of the specimens and it has been clarified that the smaller the ratio thickness/diameter is, the more often wavy cracks appear.

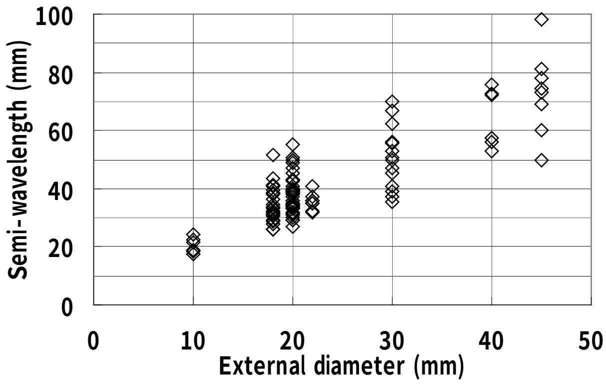


Figure 3: Relation between semi-wavelength of wavy cracks and external diameter of specimens.

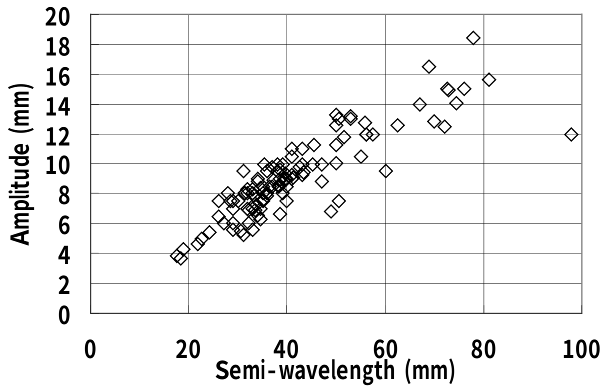


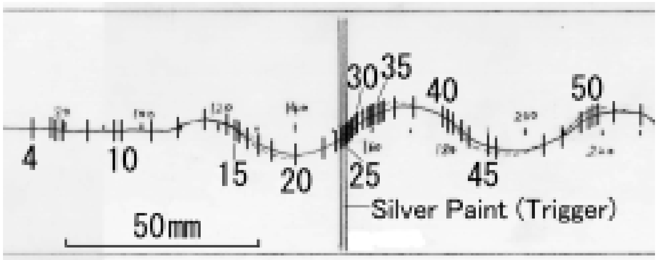
Figure 4: Relation between amplitude and semi-wavelength of wavy cracks.

For the specimens in which wavy cracks were observed, the wavelengths and the amplitudes of the wavy cracks were measured. Figure 3 shows the relation between the semi-wavelength of the wavy cracks and the external diameter of the specimens and Fig.4 shows the relation between the amplitude and the semi-wavelength of wavy cracks. From these figures, it can be concluded that the following relations hold roughly.

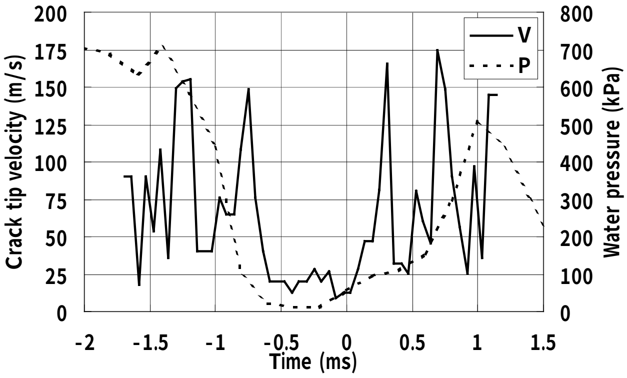
$$L \approx 4D, \qquad a \approx 0.4D.$$

In these equations, L and a are the wavelength and the amplitude of the wavy crack respectively and D is the external diameter of the specimen.

Furthermore, the wavy crack propagation was monitored by a high-speed video camera system. An example is shown in Fig.5-(a) which is illustrated using an image taken with the speed 18,000 flames per second. The numbers of this figure indicate the flame numbers. From this figure, it can be observed that the crack speed is faster when running in the axial direction than when the crack path is inclined toward the circumferential direction. Figure 5-(b) is the crack tip



(a) Crack tip positions with the flame numbers.



(b) Crack tip velocity and the internal pressure change with time.

Figure 5: An example of the crack tip positions, velocity and the internal pressure change with time obtained using a high-speed video camera system with the speed of 18,000 flames per second.

velocity and the water pressure change of the specimen with time in the case of the wavy crack propagation shown in Fig. 5-(a). Time = 0 in Fig.5-(b) corresponds to the flame number 34 in Fig.5-(a). Comparing with the shear wave velocity of glass (approximately 3,000 m/s), the crack tip speed is negligible, *i.e.*, 200 m/s at most. In general, wavy cracks never appear when the crack tip velocity is large. This matter indicates that the mechanism of the wavy crack propagation is not the effect of inertia due to the rapid crack propagation. Though the water pressure changes largely during the crack propagation, the effect of the pressure change on the crack propagation is not clear. (Even when the crack path is straight, large pressure change is observed.)

4 CONCLUDING REMARKS

In this study, glass tubes were pressurized internally by water and the behaviors of the crack propagations were observed. As the results of the experiments, the followings have been clarified.

(1) The shapes of wavy cracks are similar to one another in spite of the difference of the size

(diameter) of specimens.

(2) The mechanism of the wavy crack propagation is not due to the plastic deformation of the pressurized tube because wavy crack path was often observed even in the brittle glass tube in which almost no plastic deformation occurs.

(3) The mechanism of the wavy crack propagation is not due to the effect of inertia resulting from the rapid crack propagation because the crack tip velocity is very small comparing with the elastic wave velocity when the wavy crack propagation is observed.

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