EXPERIMENTAL STUDY OF DYNAMIC CRACKING OF PVB LAMINATED GLASS BY HIGH-SPEED PHOTOGRAPHY

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Introduction

PVB (Polyvinyl butyral) laminated glass is widely used as windshield in automotive industry. It comprises of a PVB interlayer sandwiched by two mono soda-lime glass sheets. Thanks to its impact resistance and fracture characteristics, PVB laminated glass contributes a lot to reduce the injury of the occupant in windshield-damaged accident. Therefore, it's essential to thoroughly investigate the dynamic cracking of PVB laminated glass.

Experimental solutions are adoptable for our study of PVB laminated glass since the dynamic fracture analysis involves stress waves and inertia effect which are complicated for theoretical study or finite element methods. Besides, the high-speed photography has already been proved to be an effective experimental technique in similar study on other materials [1-3].

In this paper, a new experiment method, say high-speed photography, used for studying dynamic cracking of PVB laminated specimens is introduced. The crack patterns are recorded and analyzed.

Experimental

PVB laminated specimen. The PVB laminated glass specimen is a rectangular plate, with the dimension of 200mm×150mm. A 0.76mm-thick PVB interlayer is sandwiched by two pieces of 2mm-thick glass as shown in Fig.1. During the experiment, the specimen is fixed between two steel frames attached by rubber interlayers, so that we can reduce the influence of residual stress or some possible damage to the specimen. The specimen is mounted in a drop weight tower with a 2 kg free-falling weight at 600 mm height, which provides the impact load at the center of the specimen by an impact convertor C (see Fig.3).

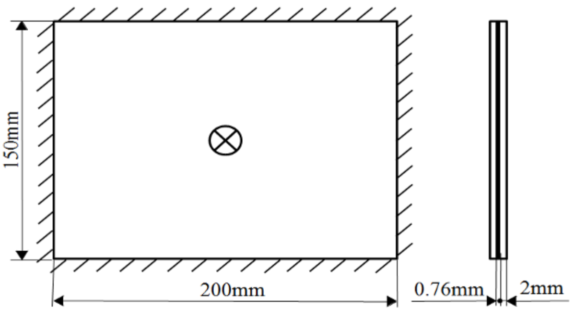


Fig. 1 PVB laminated glazing specimen

Fig. 2 High-speed photography with multi-sparks

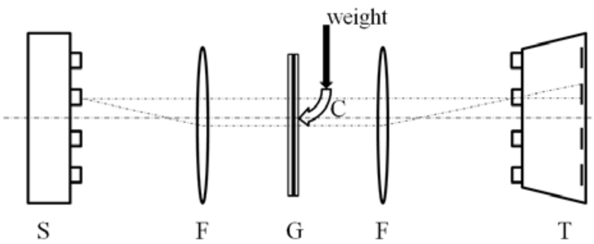


Fig. 3 Optical setup

High-speed photography and optical setup. The optical equipment of multi-spark high-speed camera is shown in Fig. 2 and Fig. 3, which includes a 4×4 array-point light source S, two convex lenses F (the objective one and the eyepiece one) with 1.55m focal length and 0.4m diameter and a 4×4 array film camera T. The specimen G is located at the mid-position between the two lenses. In this equipment, the output aperture of the spark gap is small enough to produce a focused point light source. The light rays are converted to be parallel by the objective lenses, and then transmit through the specimen and concentrate onto the film in camera T after the eyepiece. The time intervals between each two neighboring light sources can be adjusted from 1μs to 9999μs, according to the specific crack velocity. Synchronizations of the impact load with the sparks are achieved by means of a time sequence controlled circuit. As the free-falling weight contacts the surface of the impact convertor, which means cracks are going to appear, the circuit connects and thus the first spark is triggered. Afterwards other sparks are also triggered in sequence by the predetermined time intervals. Thus a series of crack images at each data collecting time are recorded by the film in camera.

Results and discussion

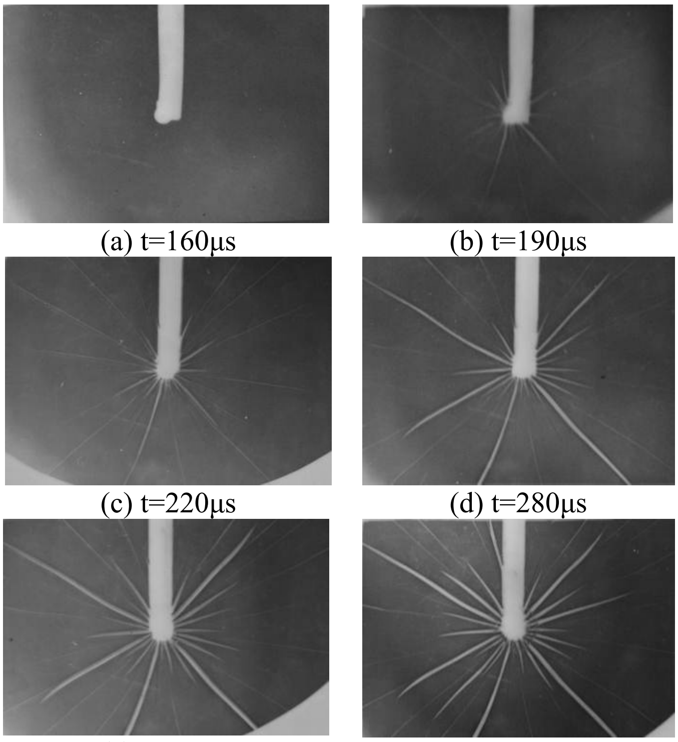
By investigating crack propagation images in chronological order and comparing to the crack patterns on the specimen, the sequence of different crack patterns that appear can be obtained. In this experiment, there are two kinds of cracks, the radial and the circumferential.

Fig.4 shows a series of high-speed photographs of dynamic cracking of PVB laminated glass specimen by setting all but one time intervals to be 30μs. In order to capture an image when the crack propagation is nearly finished, the last interval is set to 500us.

We find that at 190μs after the impact, radial cracks appear, but they are quite slender and vague. At time 280μs, the radial cracks grow thicker. Circumferential cracks don't appear until 460us after the impact.

From the comparison between the photographs and the specimen after impact, we find that it is the radial cracks in the front layer of glass that seem thick in photographs, while the ones in the back layer seem slender. Besides, the paths of radial cracks in two layers are nearly overlapped. Therefore it is possibly the refraction of light through the back cracks that make the front ones seem so thick in photographs (as aforementioned, we refer it as "growing").

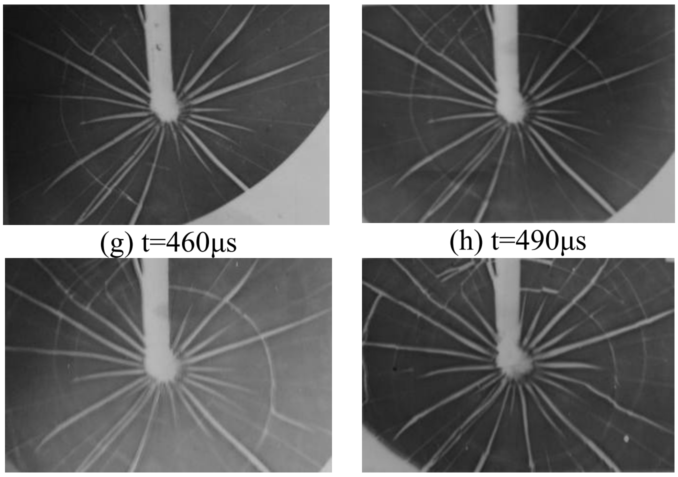
We can draw to the conclusion that radial cracks in the back layer come before those in the front layer, which is consistent with the result in [4, 5]. The circumferential cracks come last, which appear mainly in the front layer.



(a) t=160μs (b) t=190μs

(c) t=220μs (d) t=280μs

(e) t=340μs (f) t=370μs



(g) t=460μs (h) t=490μs

(i) t=520μs (i) t=1020μs

Fig.4 Propagation of cracks

Fig. 5 Specimen after impact

Conclusion

Dynamic cracking of PVB laminated glass is studied by the optical method of high-speed photography. The crack propagation is recorded from the very beginning of fracture to 1020μs when most cracks are fully developed. It is proved that radial cracks in the back layer appear first, and then come those in the front layer, and the circumferential cracks appear last, which is a critical conclusion for further numerical studies.

Acknowledgement

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References

[1] K. Takahashi, K. Arakawa: Exp. Mech 27 (1987) 195–217.

[2] X.F. Yao, G.C. Jin, K. Arakawa, K. Takahashi: Polymer Testing 21 (2002) 933–940.

[3] X.F. Yao, W. Xu, M.Q. Xu, K. Arakawa, T. Mada , K. Takahashi: Polymer Testing 22 (2003) 663-670.

[4] J. Xu, Y. Li: Journal of Automobile Engineering 223 (2009) 77–84.

[5] J. Xu, Y. Li: International Journal of Crashworthiness 14 (2009) 63–71.