DYNAMIC CRACK TIP STRESS FIELD

C. Taudou* and K. Ravi-Chandar*

The effect of dynamic and quasi-static loading on the crack tip stress field is investigated using polycarbonate specimens. Dynamic photoelasticity is used together with high speed photography to record visual evidence of a lack of K-dominance around a dynamically loaded running crack. This proof of the lack of K-dominance is used to strengthen the argument against the uniqueness of a K-v relationship.

INTRODUCTION

The stress field around a running crack tip has been established to be determined by a dynamic stress intensity factor in a way similar to the quasi-static case using a steady state analysis. Thus, a crack growth criterion can be sought in the form of a relationship between the dynamic stress intensity factor K and the crack speed v. Dally, Fourney and Irwin (1) obtained some results on Homalite 100 for different specimen geometries and different types of loading, which, at that time, allowed them to conclude in favor of a unique K-v curve.

Nevertheless, many people have questioned the uniqueness of the K-v characterization. Kalthoff (2) obtained two distinct curves for two different specimen geometries and then concluded on the non-uniqueness resulting from the geometry dependence of the K-v relationship. Similar results and conclusions were obtained by Kobayashi and Mall (3). Knauss and Ravi-Chandar (4) obtained results showing a wide variation of K for a constant crack speed.

Recently Ravi-Chandar and Knauss (5) presented a series of results illustrating a lack of K-dominance around fast running crack tip under certain types of loading.

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* Department of Mechanical Engineering, 4800 Calhoun road, Houston, TX 77204-4792, USA

Their experiments were designed to record caustics and the K values determined from caustic diameter (based on a K-field existence assumption) did not match the analytical values after the crack started running. Ma and Freund (6) corroborated this lack of K-dominance by comparing the exact solution of the normal stress $\sigma_{zz}(\xi,\theta,t)$ along the crack line and the asymptotic stress $K(t)/\sqrt{2\pi\xi}$ calculated from the only singular term. Their results showed that the two quantities differed significantly in the vicinity of the moving crack tip during some time after initiation.

Since experimental techniques assume K-dominance in the region of measurement, could this lack of dominance in such regions be the reason for the observed non-uniqueness of the K-v curve? The main objective of the present investigation is to examine the dominance of the K-field.

EXPERIMENTAL SCHEME

Both mild quasi-static loading and violent impact dynamic loading were used to initiate dynamic fracture. Quasi-static loading was realized with the specimen in the grips of an Instron machine whose crosshead moved at a constant rate whereas dynamic loading was achieved by shooting a (50mm diameter) projectile at the specimen hanging on two strings. A continuous access rotating mirror camera with a capacity of 150 pictures associated with a cavity dumped Argon ion laser light generator was used at a rate of 100,000 frames per second to record dynamic photoelastic fringe patterns. Dynamic photoelasticity was preferred upon dynamic caustic for *the existence of "butterfly" loops generally observed is a necessary condition for a K-dominant stress field to exist near the crack tip*. It is believed that if the field is not dominated by the stress intensity factor then the typical "butterfly" loops should collapse into some other patterns.

A series of experiments was made on Polycarbonate (GE LEXAN) specimens 6.35mm thick, 400mm long and 100mm wide with a 15mm long sharp precrack on the longitudinal edge. Quasi-static loading tests were run with a cross head displacement speed of 5mm/s, the grips were attached along the whole width of the sample, and a conductive paint wire was located ahead of the crack tip to trigger the camera at the appropriate time; no pictures of the loading stage could then be recorded. Dynamic impact loading tests were achieved with a projectile speed of 39m/s. In this particular case, pictures of the loading stage could be obtained since the camera was triggered by a beam interruption prior to specimen impact.

Figures 1 and 2 present a sequence of 10 chosen frames extracted from a series of pictures taken every 10μs showing the isochromatic fringe patterns obtained. In both cases, the crack speed was measured to be about 400m/s and constant as the crack propagated. It is obvious that a great deal of difference exists in both patterns, illustrating an indubitable difference in the stress fields around the moving crack tip for the two types of loading. A magnified view of a selected frame 60μs after initiation is shown in Figure 3.

Even though the fracture was brittle in both experiments, the crack surfaces depict very dissimilar features. It was observed that the damage zone on the dynamically loaded specimen was much deeper than the one of the quasi-statically loaded specimen.

DISCUSSION

On the one hand, the quasi-static loading leads to the "butterfly" loops which are similar in form to what has been obtained by others (1). Notice from Figure 1 that the "butterfly" loops appear only after the passage of the shear wave emanated from the initial crack tip. The typical "butterfly" loops indicate that the necessary condition for the existence of a K-dominant field has been satisfied. The dynamic stress intensity factor might be determined from such loops, although the effect of higher order terms in the steady state expansion might have to be considered.

On the other hand, the stress field existing around the moving crack tip as a result of the dynamic loading has to be considerably different. Very small "butterfly" loops can be observed at the crack tip before crack initiation (100μs) but they completely disappear when the crack breaks away. The loading and propagation phases exhibit a peculiar feature: a frontal lobe. This lobe, which appears in the loading phase and takes over the small "butterfly" loops when the crack runs, extends about 15mm ahead of the crack tip; it is caused by the biaxial field imposed by the projectile. Clearly the K-field does not establish dominance over the same lengths as in the quasi-static loading. Further work is in progress to evaluate quantitatively the range of dominance of the K-field under different loading conditions

CONCLUSION

It has been shown that the dynamic stress field around a crack tip is not dominated by the K-field under different loading conditions. The lack of K-dominance implies that K-v characterizations have to be reevaluated.

REFERENCES

(1) Dally, J.W., Fourney, W. L. and Irwin, G. R., Int. J. of Fracture, Vol. 27, 1985, pp. 159-168.

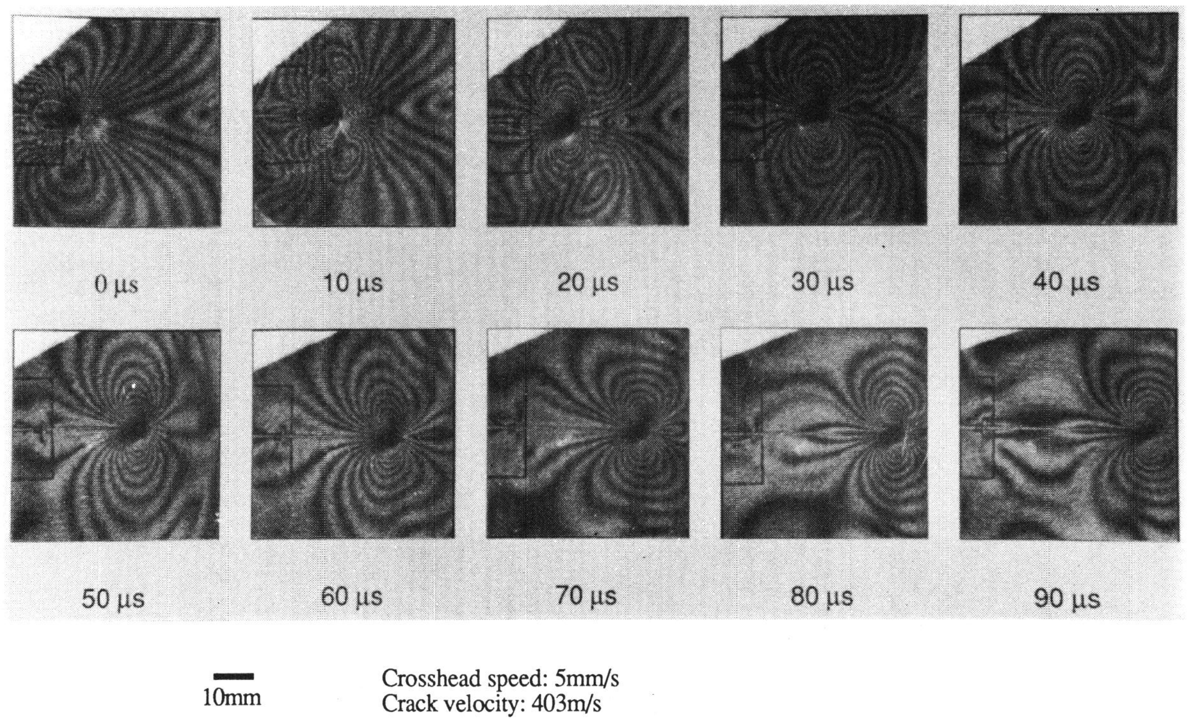
(2) Kalthoff, J. F., Workshop on Dynamic Fracture, California Institute of Technology, 1983, pp. 11-25.

(3) Kobayashi, A. S. and Mall, S., Experimental Mechanics, Vol. 18, 1978, pp.11-18.

(4) Knauss, W. G. and Ravi-Chandar, K., Int. J. of Fracture, Vol. 27, 1985, pp. 127-143.

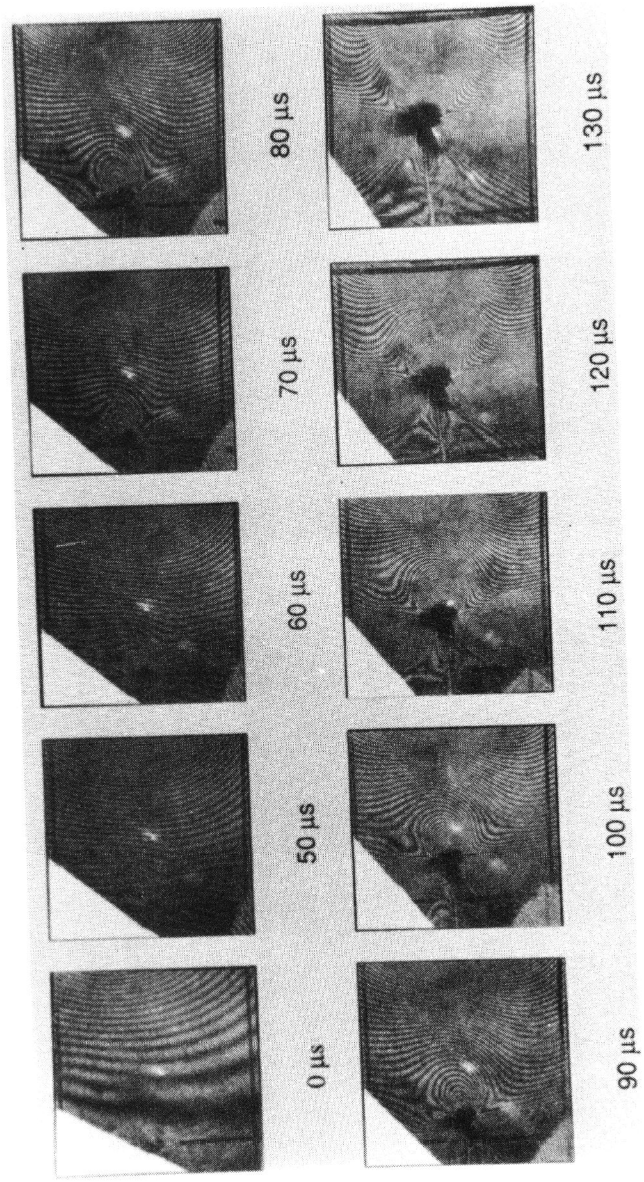
(5) Ravi-Chandar, K. and Knauss, W. G., J. of Applied Mechanics, Vol. 54, 1987, pp. 72-78.

(6) Ma, C. C. and Freund, L. B., J. of Applied Mechanics, Vol. 53, 1986, pp. 303-310.



Crosshead speed: 5mm/s
Crack velocity: 403m/s

Figure 1: Dynamic photoelastic fringes on quasi-statically loaded specimen



10mm

Bullet speed: 39m/s
Crack velocity: ≈400m/s

Figure 2: Dynamic photoelastic fringes on dynamically loaded specimen

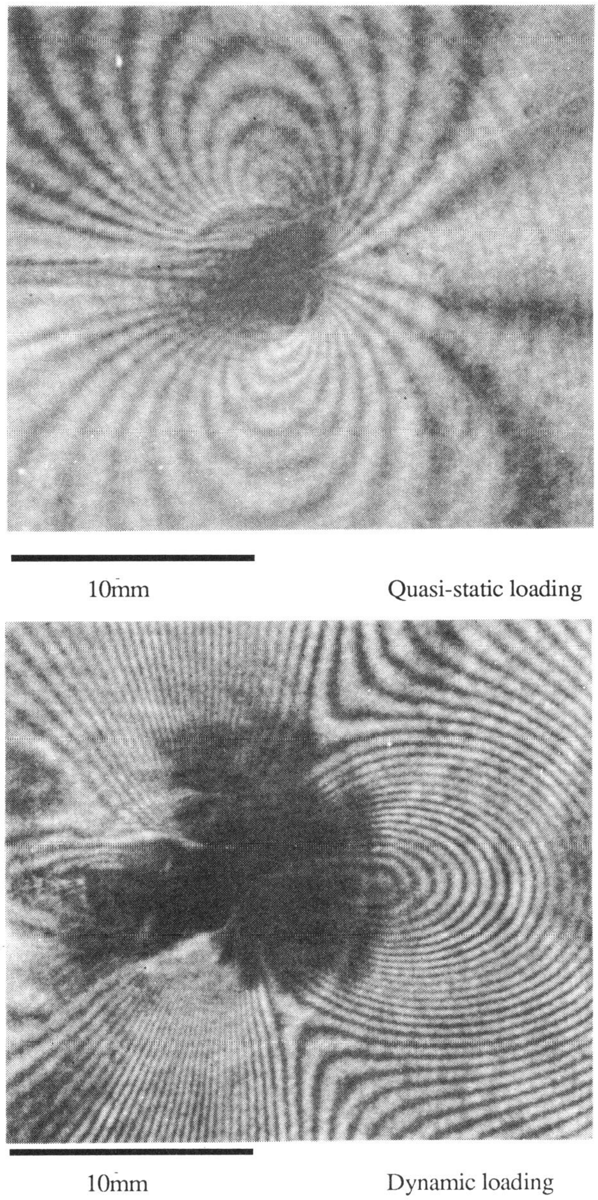


Figure 3: Photoelastic fringe patterns 60μs after crack initiation for different loadings