Dynamic Study of Subcritical Crack Growth in Coarse-grained Aluminum

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Technical Report No. 578, March 1990

Dynamic Study of Subcritical Crack Growth in Coarse-grained Aluminum[1]

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Abstract

The phenomenon of subcritical crack growth in aluminum tensile specimens with average grain size ranging from 3.5 to 12 mm were studied using an electro-optical dynamic testing system and moire techniques. Moire fringe patterns were recorded using a digital high speed camera coupled with a copper vapor laser. Strain and strain rate distributions ahead of the crack tip were obtained quantitatively. In this study we observed grain boundary sliding along between some grains, whereas the relative rotation of each individual grain characterized by mechanical twining was absent. We also observed that along the line of crack tip propagation, the strain component and strain rate component both normal and parallel to the direction of applied loading attended minimum value, and the velocity of crack propagation was much influenced by the microstructure of the materials. In all the tests, the crack always propagated towards the triple or quadruple points. The crack traveled with maximum velocity near the center of a grain and assumed much slower velocity near the triple or quadruple points.

1 Introduction

Dynamic fracture of metals have been one of the most active research field for many years. Crack initiation and growth in metals are generally considered

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[1] Work supported by ONR Contract No. N0001482K0566 (Scientific officer: Dr. Yapa Rajapakse)

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to be either in brittle manner or in ductile manner, depending upon material microstructures and testing conditions. The important role of material microstructure features played in the dynamic fracture process have been studied by numbers of researchers (*F. A. McClintock*[1], *D. A. Shockey et al*[2], *P. K. Wright*[3], *W. C. Leslie*[4]), and considerable results have been published in recent years.

In study ductile crack propagation in f.c.c. crystals (such as aluminum), crack grow under applied loading. If the applied stress is sufficient, the crack would instantaneously propagate at about 2/3 of the sound speed (*A. S. Krausz* and *K. Krausz*[5]). However, in most of the cases, the crack start propagation at a much slower velocity when applied stress are still far below the critical value. The process of crack propagation at slower velocity are considered as subcritical crack growth. The speed and direction of crack growth are determined by plastic deformation ahead of crack tip, it in turn are very much influenced by micro-parameters such as material microstructure and internal energy, and macro-parameter such as loading conditions.

In case of shock wave induced spalling, large number of microvoids or microcrack attendant (*M. A. Meyers* and *C. T. Aimone*[6]). Crack propagated as the result of growth and coalescence of these microvoids. The average crack growth velocity are therefore higher. *D. A. Shockey et al*[7] investigated the effect of grain size on dynamic fracture behavior of α-titanium. They found that the rate of propagation of damage was much higher for the small-grained material. This is due to the higher density of microvoids nucleaed at grain boundary triple points. By study the effects of density of pre-existing dislocations, the stacking fault energy, and the solid state precipitation on dynamic fracture, *W. B. Jones* and *H. I. Dawson*[8] presented the significance of the role of metallurgical parameters in the dynamic behavior of materials. Under extreme dynamic loading conditions (the strain rate during application of load may be as high as $10^5 sec^{-1}$), *L. Seaman et al*[9] were able to show that normally ductile materials may fracture in a brittle mode, i.e. by activation and propagation of microscopic planner cracks. But for high purity aluminum and several other ductile metals, these ductile-brittle transition were absent (Temperature effect are not concerned here). Aluminum fracture under impact conditions by nucleation and growth of spherical voids similar to those normally observed in quasistatic tests. All thses studies are phenomenonaligical in nature. There are very few studies of material microstructure influence on subcritical growth of a pre-existed crack.

This paper present a experimental study of subcritical crack growth in coase-grained aluminum. A series of tensile specimens with edge fatigue crack were tested using an electro-optical dynamic testing system. Average grain size of each specimen were ranging from 3.5 to 12 mm. Strain field and strain rate field were quantitatively obtained. The results show that microstructure of the material have a great influence on subcritical crack growth.

2 Experiment

Classical moire method was employed with our electro-optical dynamic testing system to study subcritical crack growth in coase-grained aluminum (Experimental set-up was schematically shown in Fig. (1)). Tensile specimens of pure aluminum (99.9%) were specially prepared to obtain large grains. A edge crack of 3 mm in length (about thickness of the specimen) was induced by low cycle fatigue method. Specimen surface were then polished and etched in standard solutions. A line grating of $500lpi$ was printed onto the specimen surface parallel or perpendicular to the crack surface. The contract of printed gratings were so controlled that the grain boundaries on specimen surface were clearly visible. A reference grating of the same frequency was superimposed on the printed grating, and moire fringe patterns during the process of dynamic fracture were thus recorded suing a high speed digital VCR system coupled with a copper vapor laser with pulse duration about $30nsec$. Recorded image of moire fringe patterns were then played back for examination and analysis. Loading history were also recorded through a data acquisition unit connected with loading machine and an IBM -XT personal computer system. Digitized moire fringe patterns are shown in Fig.(2 , 3). Contours of strain and strain rate components ahead of crack tip are depicted in Fig.(4 , 5 , 8). Fig.(7) shows the speed and trace of crack tip propagation.

3 Results and discussion

In this experimental study, special interests were focused on the microstructure influence on the direction and velocity of subcritical crack growth. Strain field and strain rate field were quantitatively obtained at each consecutive stage during dynamic fracture process.

Grain boundary sliding were observed (Fig.(3)) along between some grains whereas relative rotation of each individual grain characterized by mechanical twining were absent (*X. M. Li* and *F. P. Chiang*[10]). Strain concentration at some points along grain boundaries or grain boundary triple points were also presented similar as in static deformation.

Fig.(4 , 5 , 8) show that along the direction of crack tip propagation, strain components and strain rate components both parallel and perpendicular to the loading direction were attended minimum values. In all the tests, crack would initially propagate towards grain boundary triple points, where stress concentration were higher, and consequently plastic energy stored in the region were higher which favored the crack tip opening. On the other hand, the accommodation requirement for plastic deformation near triple points resulted in a more complicated microstructure. Difference in orientation of neighboring grains, dislocation loops, dislocation cell structures near the triple points would all appeared as obstacles for crack tip propagation. Thus as we observed in Fig.(7) crack advanced much slower near those triple points and propagated with maximum velocity at the center of grain where less difficulties for crack tip propagation were assumed.

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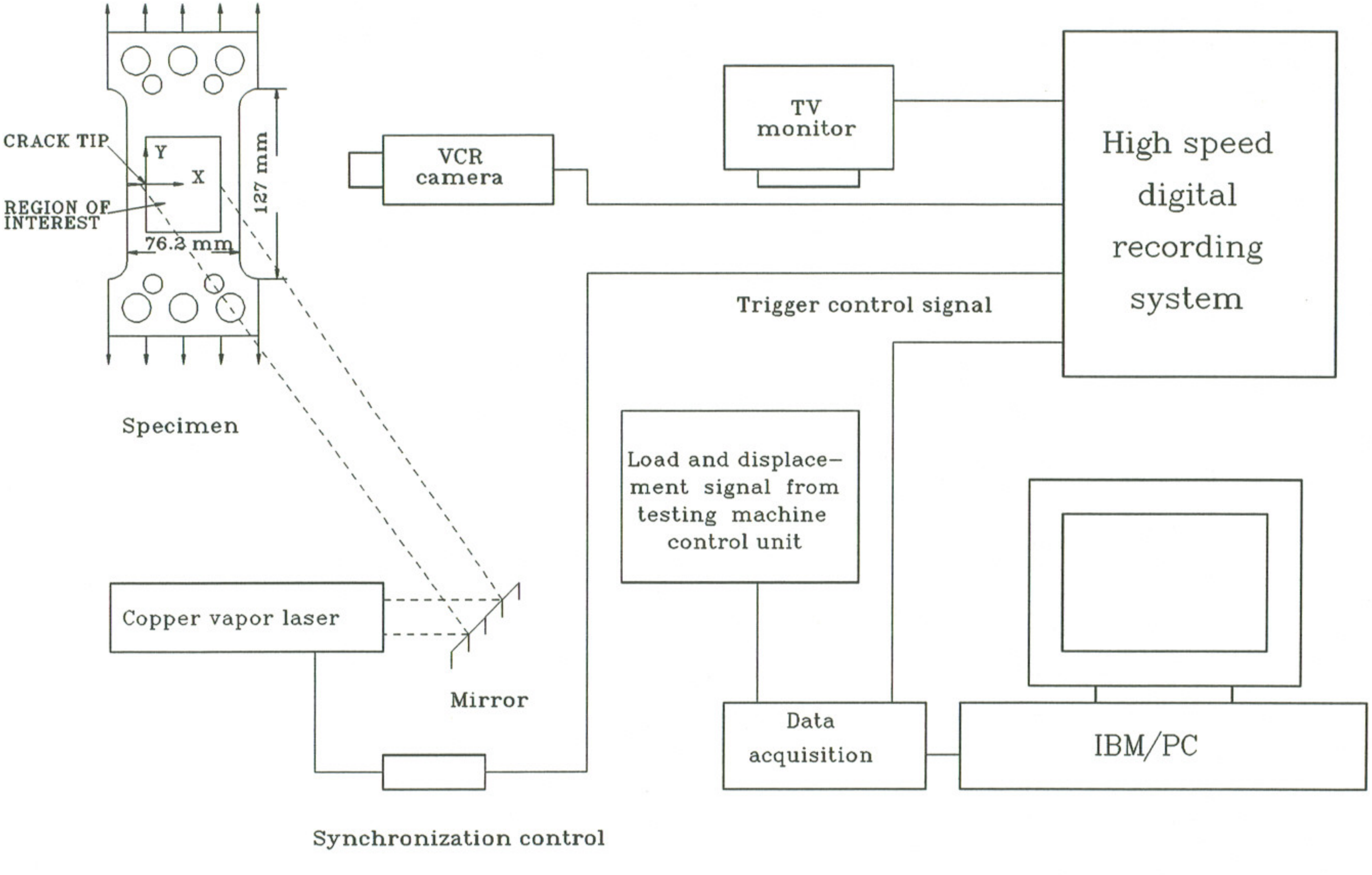
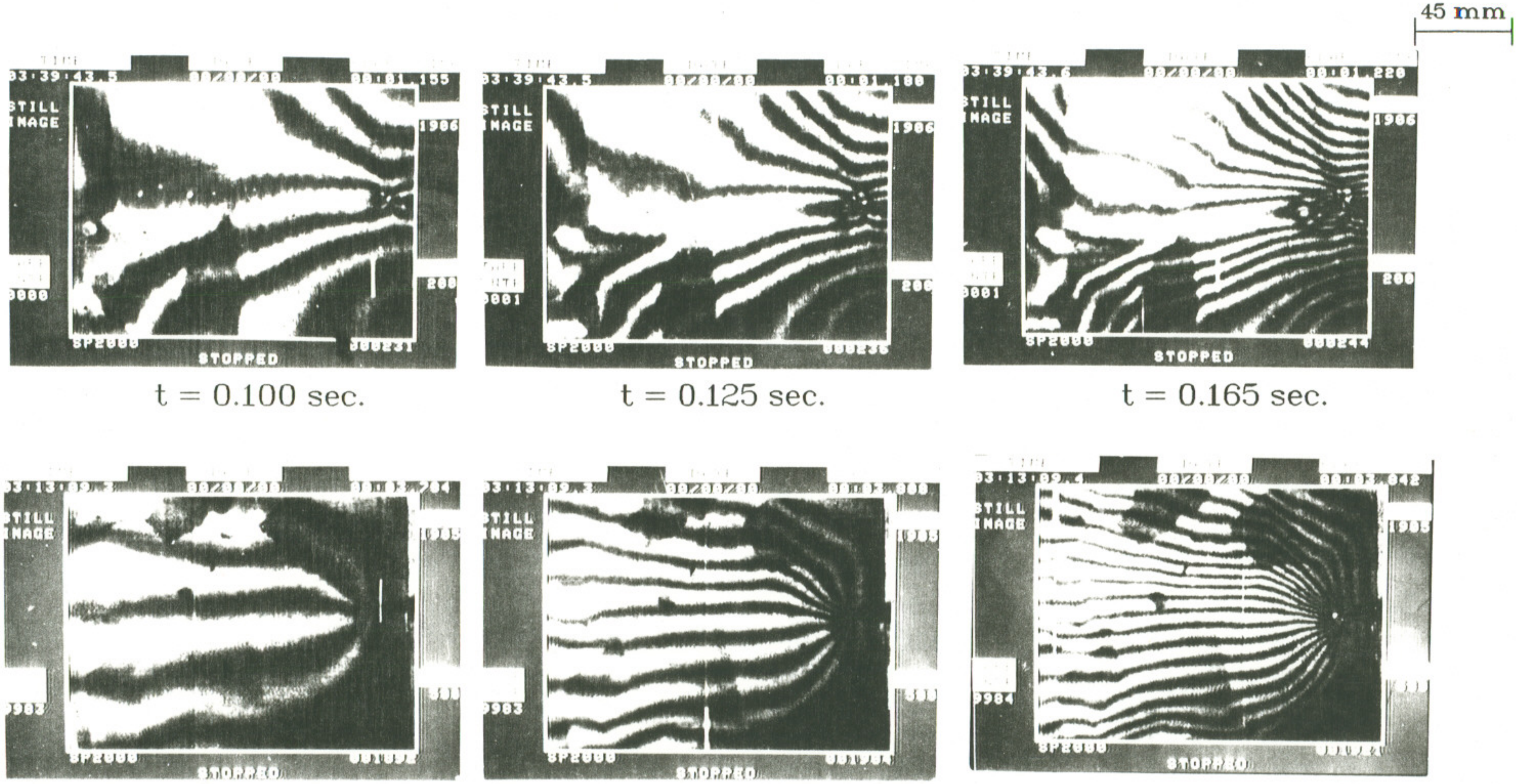


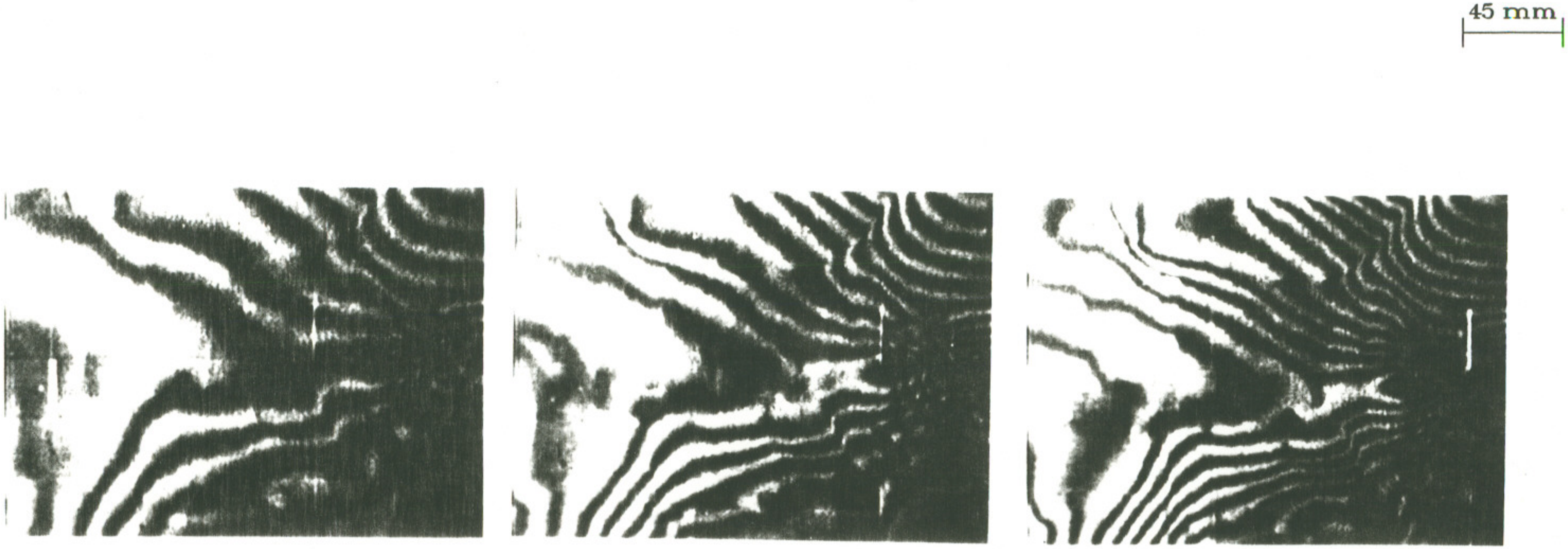
Fig.(1) Electro–optical dynamic testing system



t = 0.100 sec. t = 0.125 sec. t = 0.165 sec.

t = 0.084 sec. t = 0.108 sec. t = 0.142 sec.

Fig.(2) U–field (Top) and V–field (Bottom) moire fringe pattern obtained at 200 frames/second and 500 frames/second respectively



t = 0.156 sec. t = 0.190 sec. t = 0.232 sec.

Fig.(3) U–field moire fringe pattern obtained at 500 frames/second

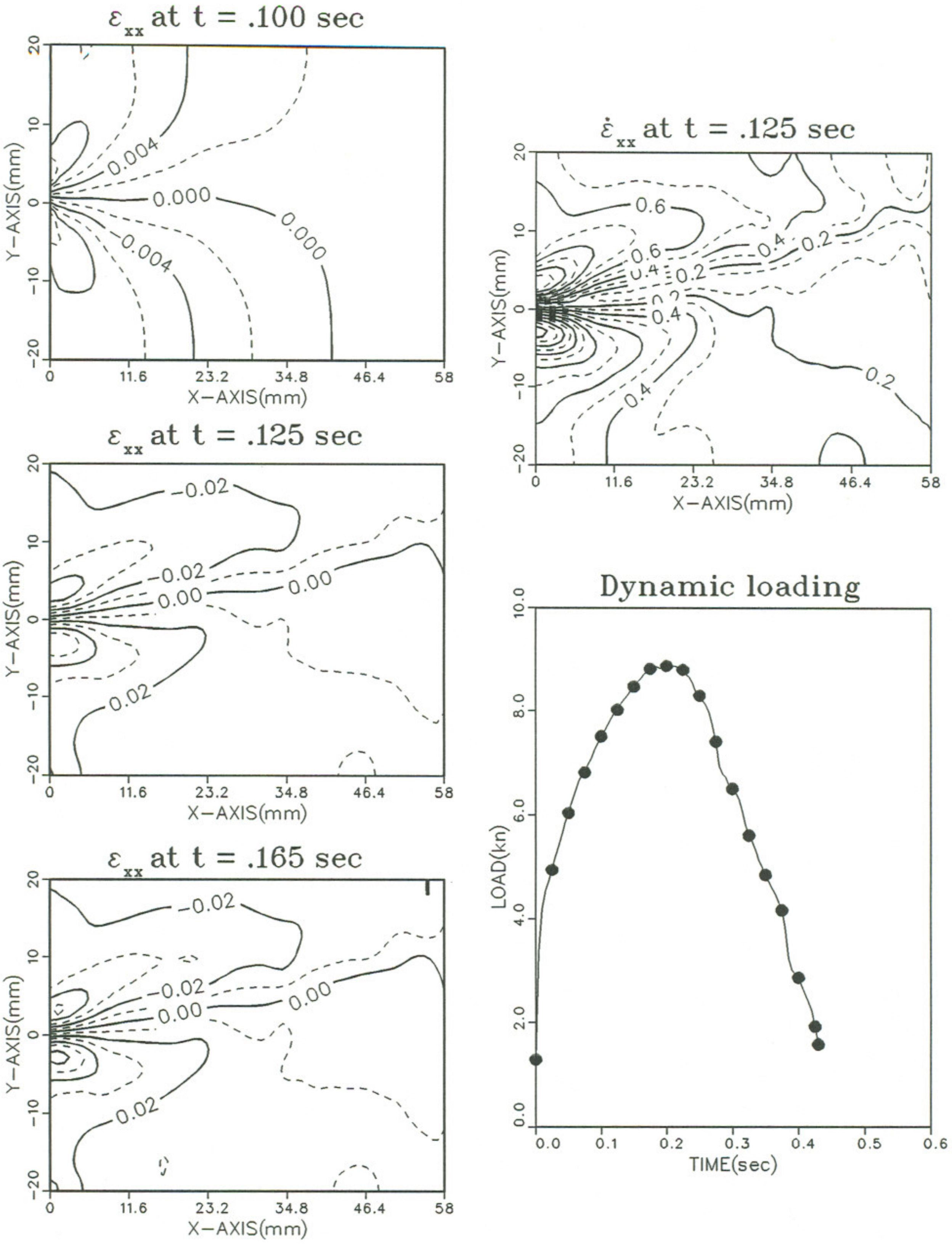
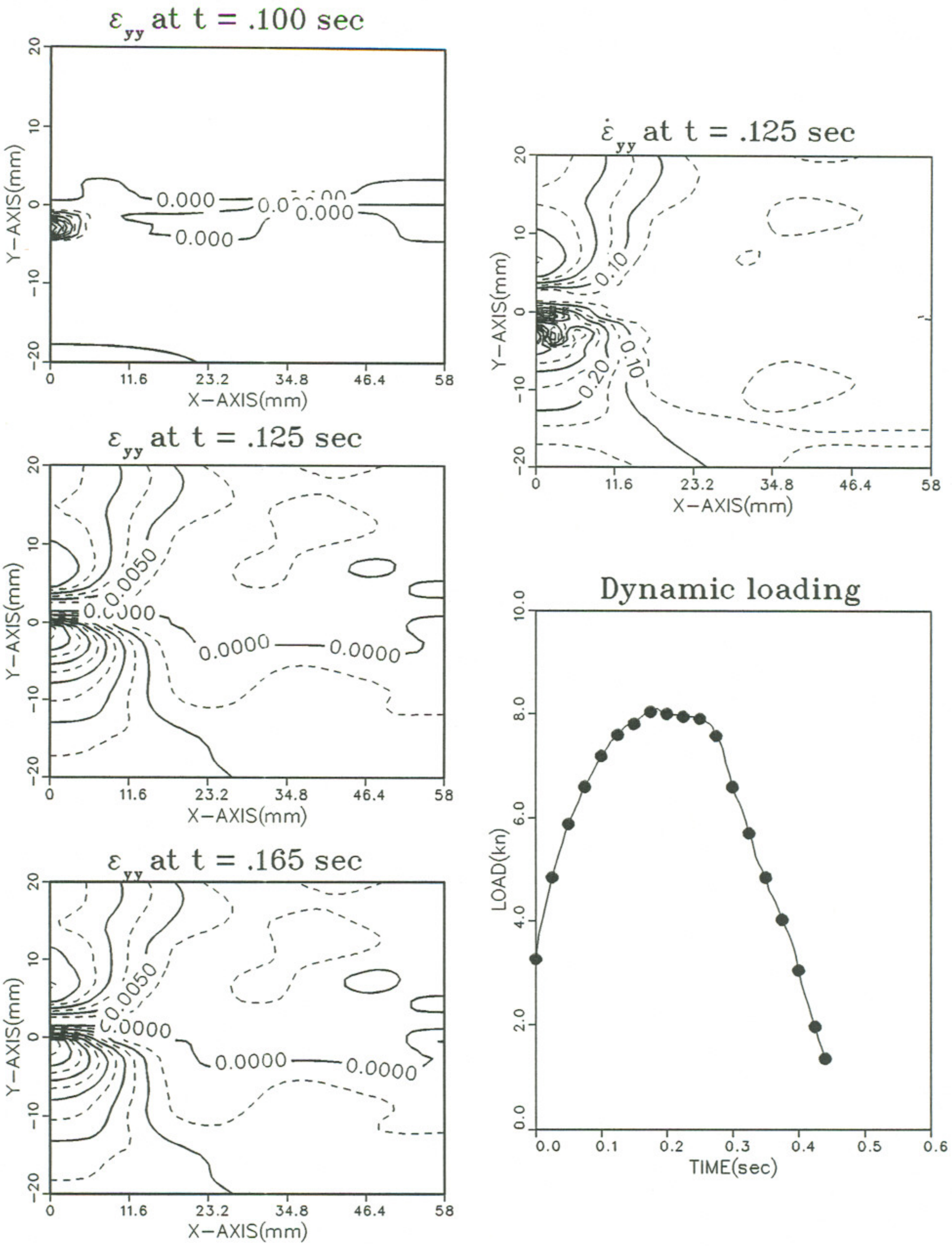


Fig.(4) Contours of strain component ε_{xx} and strain rate components $\dot{\varepsilon}_{xx}$



ε_{yy} at t = .100 sec

$\dot{\varepsilon}_{yy}$ at t = .125 sec

ε_{yy} at t = .125 sec

Dynamic loading

ε_{yy} at t = .165 sec

Fig.(5) Contours of strain component ε_{yy} and strain rate components $\dot{\varepsilon}_{yy}$

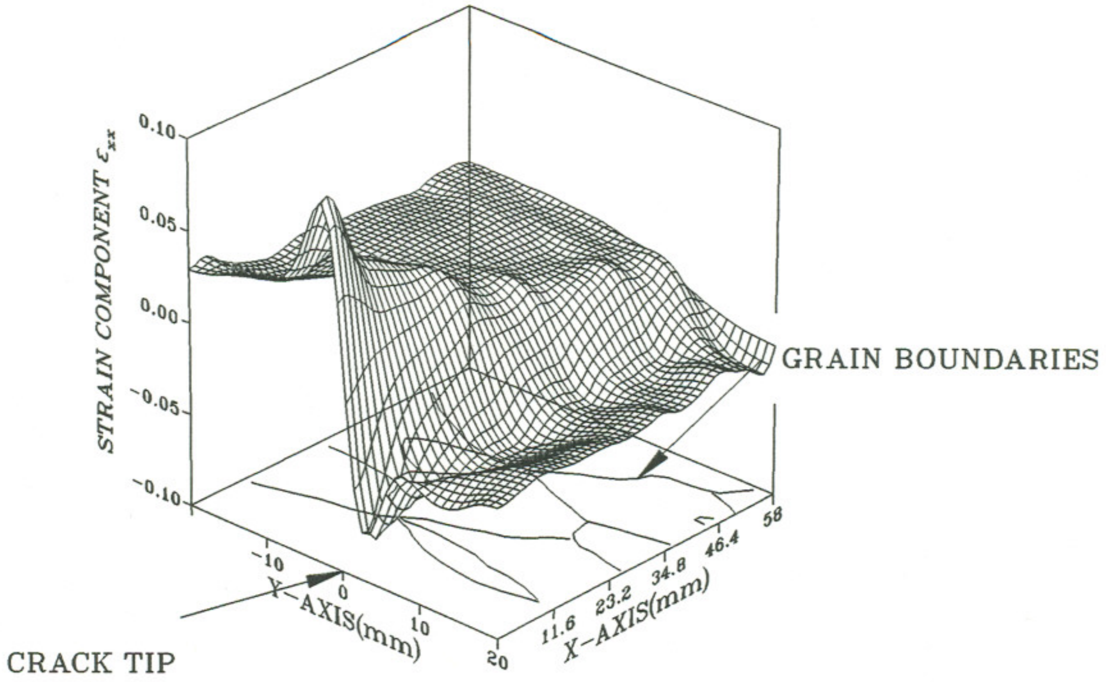


Fig.(6) Distribution of strain component ε_{xx}

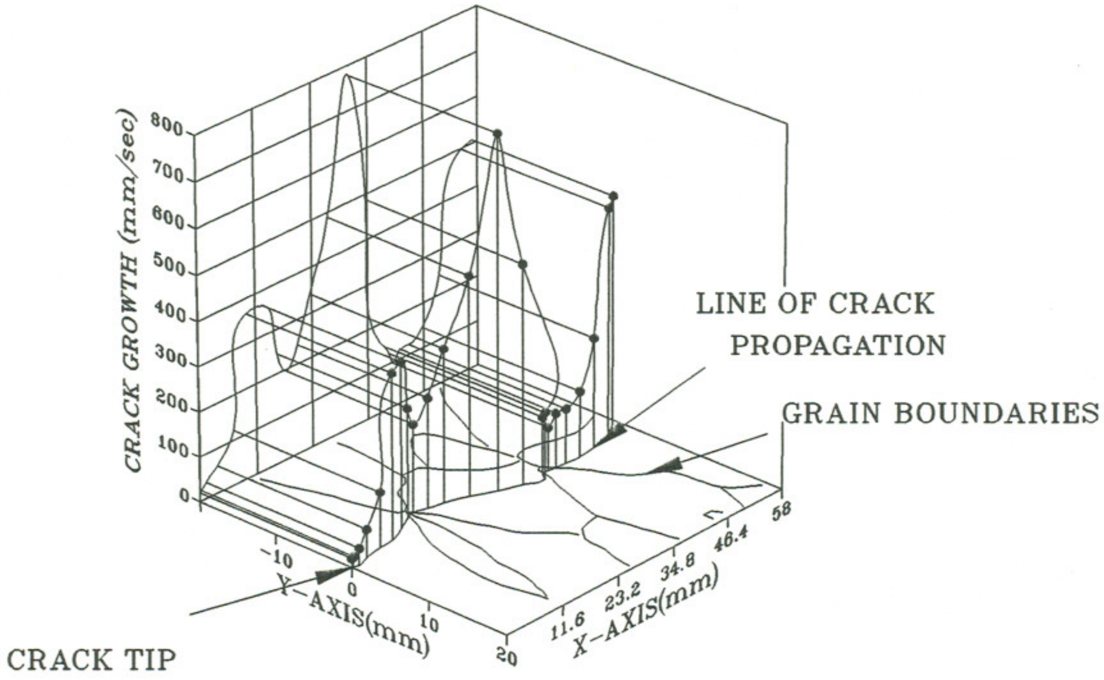


Fig.(7) Subcritical crack growth