FAST CRACK GROWTH - A NEW THEORETICAL APPROACH

Z.Lis, A.Neimitz *

In the present article the computer simulation has been applied in order to verify numerically an equation of the fast crack growth, presented during the last EGF conference in Torino.
The results obtained are in the qualitative agreement with experimental observation.

INTRODUCTION

Present article is a continuation of two papers presented during ECF8 conference in Torino. It includes a computer simulation of the model of crack kinetics and equation of crack motion presented in (1),(2).

The purpose of the work reported in these series of papers is to provide a deeper understanding of the fast crack growth phenomenon and to propose a proper tool to solve more realistic problems than those considered in the present research. The computer simulation is the first step to confirm or deny the proposed theory. If results of the computer simulation were qualitatively similar to the experimental observations it would be encouraging to invest more efforts in the expensive and time consuming experiments and numerical (finite elements) computations.

Recent experimental findings obtained with the help of modern techniques have shown that existing theories, describing fast crack motion are not sufficient to explain certain phenomena observed experimentally. However, direct comparisons between theoretical and experimental findings must be performed very carefully since theoretical modeling concerns usually infinite bodies while experiments

* Kielce University of Technology, Kielce, Poland

are typically conducted upon relatively small specimens and the presence of wave reflections and interactions lead to a very complicated stress histories at the crack tip. Nevertheless, relatively long list of the characteristic features of the fast crack growth can be made and compared with theoretical models:

1. Between crack initiation and possible crack arrest the crack travels at some velocity governed by the applied loading and the material properties. Within the resolution of the experiments performed (5 μsec), no continuous acceleration of the crack tip could be observed. In some experiments the crack tip deceleration prior the crack arrest has been observed, eg. (3), in others an abrupt arrest has been noted, eg. (4)

2. All materials exhibit a limiting crack speed which is on the order of one half of the shear wave speed c_T or less (5) (6).

3. The crack velocity remains constant, and independently so of whether the stress intensity factor decreases, remains constant or increases - provided changes in the stress intensity factor does not occur due to rapid wave interaction (7).

4. The velocity with which the crack propagates is determined by the stress intensity factor at initiation (3),(7).

5. There is no unique relation between the instantaneous stress intensity factor and the crack tip speed. This statement seems to be well documented experimentally at the moment (7),(8) although many authors reported such a behaviour in the past (9),(10).

6. Existence of the arrest stress intensity factor has not been proven to be a material constant.

RESULTS OF THE COMPUTER SIMULATION

In (1) and (2) all details of the crack and crack kinetics models have been presented as well as analytical formulae following from the computations of the so called "driving force" on the moving crack tip and the strip yield zone. The results obtained have been a motivation to postulate a new form of the crack motion equation. Although, the crack motion equation can be considered as a valid for this one, discussed here model only, one can also expect its more general nature. It is generally based on the driving force $\mathcal{G}^d_{III}$ concept that is understood here as an energy flux into the plastic zone from the surrounding material. In general the equation of the crack motion can be written in the form:

$$\mathcal{G}^d_{III}(\sigma, a, v_L, v_T, \text{geometry}) = \mathcal{G}^d_{IIIc}(v) \qquad (1)$$

where σ is external stress, a is crack length, v_L and v_T are the leading and trailing edge velocities of the crack respectively, $\mathcal{G}^d_{IIIc}$ is the critical value of the driving force that can be defined as a time derivative of the energy consumed during creation of a new crack surface (including energy dissipated for plastic deformation). If this energy is expanded into series around steady state one can obtain:

$$\mathcal{G}^{d}_{IIIc}(v) = \mathcal{G}^{d}_{IIIc}(v=v_{ss}) + \frac{\partial M}{\partial t}(v-v_{ss}) + M\frac{\partial v}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where $M=\partial\Gamma/\partial t$ and Γ is an energy consumed during crack propagation.

When Eq.(2) is utilized in Eq.(1) one obtains equation that is similar in form to the equation of crack motion proposed in (2). Since the quantity Γ is difficult to define, the function M was interpreted as a "equivalent" mass of the plastic zone (computable) leading to the Newton's - like equation of the plastic zone motion. Adopting this interpretation the first term on the right hand side of Eq.(2) represents the resistance of the material to the crack propagation, the second one the change of the plastic zone size and third one the acceleration\deceleration of the crack tip (plastic zone)

The above equation of crack motion has been utilized within computer simulation adopted to the strip-yield zone model of the crack and the crack kinetics proposed in (1). Details of the computational procedure and algorithm have been presented in (11) although for simpler case (without the second term in the r.h.s. of, the Eq.(2)). In the present article the results of the computer simulation will be presented along with the conclusions. Because of the limited space only some results will be presented, more will be shown during presentation.

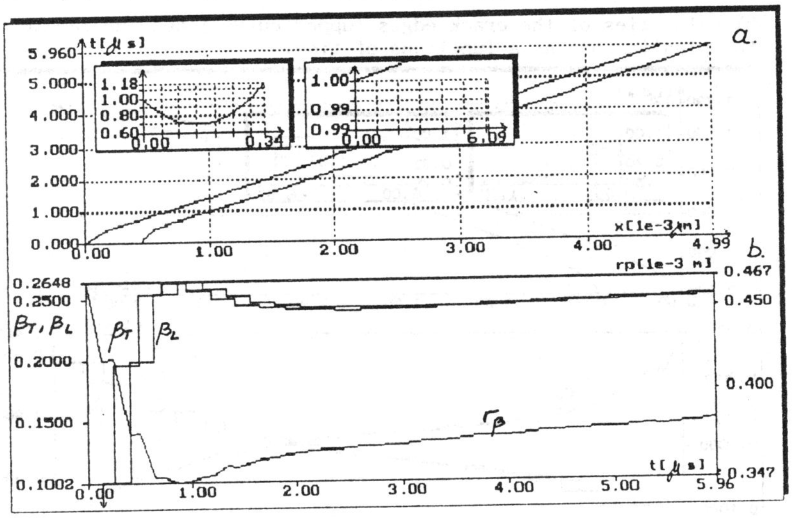

Figure 1 a) leading and trailing edges trajectories and the schemes of the material function (minimum at v/c_T=.15) and loading history b) velocities of the crack tips (upper curves) and the length of plastic zone as a functions of time.

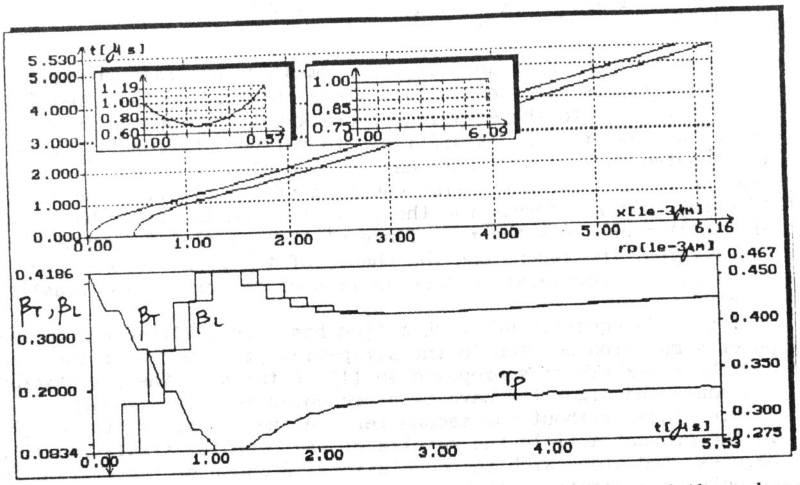

Figure 2 a) Leading and trailing edges trajectories and the schemes of the material function (minimum at v/c_T=.25) and loading history b) velocities of the crack edges (upper curves) and the length of the plastic zone as a functions of time.

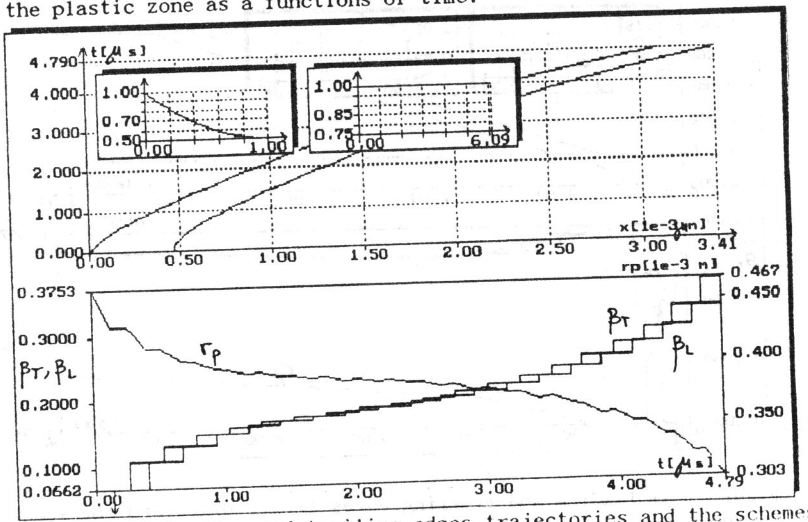

Figure 3 a) leading and trailing edges trajectories and the schemes of the material function (decreasing with v) and loading history b) velocities of the crack edges (lower curves) and the length of the plastic zone as a functions of time.

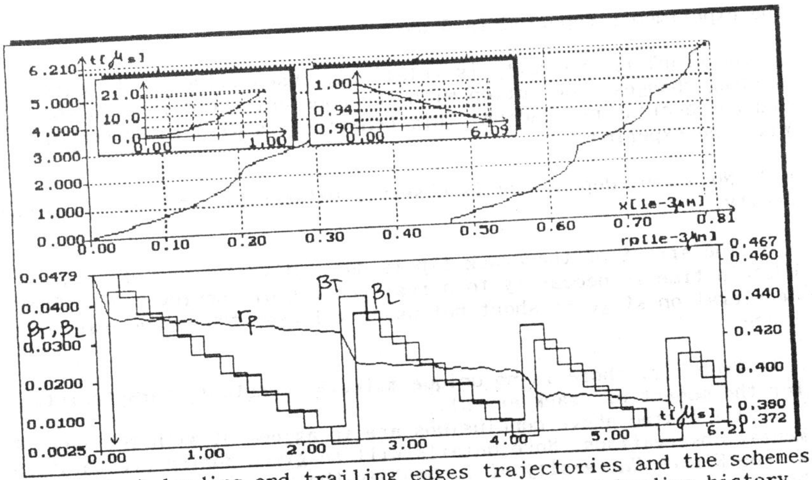

Figure 4 a) leading and trailing edges trajectories and the schemes of the material function (increasing with v) and loading history b) velocities of the crack edges and the length of the plastic zone as a functions of time.

CONCLUSIONS

More than eighty simulations have been performed providing interesting conclusions concerning fast crack motion according to the presented model. We will compare these results with the main features of the fast crack growth listed in the first section of this paper.

1. The simulations were performed assuming various external loading histories (constant, increasing and decreasing in time) and various shapes of material function $g^{d}_{IIIc}(v=v_{ss})$ (type "a" - increasing with crack velocity; parabolic, type "b" - parabolic with maximum at v=0; decreasing with crack velocity, type "c" - parabolic; decreasing with crack tip velocity for small velocities and starting from certain threshold value an increasing function, type "d" - parabolic with minimum for $v/c_T= 1$; decreasing with crack tip velocity).

It may be concluded from the results obtained that the material function of a type "c" provides the best qualitative characteristics of the crack kinetics during unstable crack growth. Functions of the "a" and "b" type require increasing external loading to make crack moving. Function of a "d" type leads to a crack tip speed much higher than .5 c_T. For all "a","b" and "c" functions one may observe limit crack tip speed much smaller than c_T.

2. In all simulations it was observed that crack tip accelerates to its more or less constant velocity in the very short time interval, smaller than 4 μsec. In general, this result is not in contradiction with the experimental observation since the resolution of

the experiments reported is 5 μsec.

3. The crack tip velocity is relatively insensitive on the external loading changes. The motion with the constant speed is also observed for decreasing loading. This behaviour is also in agreement with the experiment.

4. No unique dependence is observed between SIF and crack tip velocity.

5. The arrest of the crack tip is not a discontinues process. A certain time is necessary to arrest the rapidly moving crack. The deceleration stage is short but usually longer that acceleration stage.

6. Probably, there is no unique material constant characteristic for the moment of crack arrest.

All listed above conclusions are in agreement with the experimental observations. More details will be given during presentation At the Kielce University of Technology the experimental program is being prepared to verify presented here equation of motion.

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