On Dynamic Crack Propagation - A Literature Study

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1 INTRODUCTION

The impact on elastic bodies might have been studied as early as 1856 by Cox followed by Saint-Venant (1883), Timoshenko (1913) and others (Mason, H. L. 1936; Arnold, R. N. 1937; Lee, E.H. 1940). But during the early stages the studies were mainly restricted to analytical investigations which involved tedious methods of numerical solutions with sufficient patience. With the developments of better numerical methods and invention of fast computers the investigations have become less difficult.

Measuring dynamic material strength values is a complex procedure as there are several effects whose influences are to be considered. Amongst those time and size effects are two important factors. Different tests are now being employed for the studies of material values at fracture initiation and propagation properties of material, of which 'Dynamic Tear Test' or 'Drop Weight Test' is one of the tools which involves transverse impact by means of a mass on a beam.

Modern structures are often subjected to dynamic loading. Hence the determination of the dynamic fracture toughness values, in particular, the crack arrest toughness and of the initiation fracture toughness at high loading rates has become an essential aspect of present investigations. The present work is primarily based on the literature survey on the dynamic stress analysis with a specific attention to the determination of the stress intensity factor 'K' for three-point bend specimens.

2 DEVELOPMENTS

2.1 Improvement of Ideas

Regarding the mechanical aspects of the dynamic tear test, the work of Nash and Lange (1969) may be mentioned. However, the authors had difficulties in finding the time at which the fracture was initiated. Some aspects which were either missed or not explained by the authors have been treated by other authors later on (Brock, L. M. et al. 1985). Kolsky (1985) pointed out that determination of the loading wave forms associated with dynamic fracture can be important in characterising the process. This prompted Brock et al. (1985) to view the complicated wave pattern as a combination of two waves, the impact wave and the reflected waves. Previously it was also observed that the

fracture in dynamic tear test occurs due to a notch end stress state generated by complicated pattern of impact and reflected waves (Congleton, J. 1973; Shockey, D. A. et al. 1983).

On the dynamic analysis of impact test specimens, very recently Peuser (1983) has put forward two methods by means of which dynamic behaviour of impact test specimen can be analysed : (i) Finite Difference Scheme, and (ii) Method developed on the basis of former results (based on beam theories). The finite difference scheme seems to be an approximate method to investigate the dynamic behaviour of impact test specimen. On the other hand the results of the beam theory are closer to numerical data than to the experimental one. A series of experiments on several specimens having different geometry have been conducted (three-point bend specimens) by Gross, D. and his co-research workers (Peuser, T. 1983; Zhang, C. 1986; Zhang, C. et al. 1987; Böhme, W. 1985). The time effects and their influences on test procedures for measuring material strength values have been investigated by Kalthoff (1983) covering many aspects including the studies the behaviour of specimen under impact loading by measuring the reaction at the anvils (Kalthoff, J. F. et al.1983). The observations made by Kalthoff is significant in respect of the fact that for measuring the dynamic fracture toughness value, instrumented impact test the $K(STAT)$ values would represent a good approximation of the actual dynamic stress intensity factor $K(DYN)$, for times larger than $3-\tau$ (τ being the period of eign oscillation of the impacted specimen) as claimed in Draft 2C, American Society for testing and Materials (1980) was questioned. Kalthoff's investigation (1983) confirms that a static analysis is not adequate to describe the dynamic loading condition. Moreover, τ -value may be reduced by the reduction of the specimen dimension, but these conditions are very unfavourable for testing of brittle materials at high impact velocities. Kalthoff also warns against the use of electronic devices with low frequency response. On the study of finite element analysis of an impact test, Abersen et al. (1977) have put forward a critical study of the programme employed by Madison and Irwin (1974) for a pre-cracked three-point bend specimen. It has been observed that considerable difference between the dynamic and quasi-static responses is exclusively the result of specimen inertia.

2.1 Use of J-Integral

For the safety of nuclear reactor design power, generating services operating nuclear reactors are now keenly interested in the developments of elastic-plastic fracture mechanics. Many elastic-plastic theories have been proposed with different parameters and criteria. Tests are being performed to check their validity. The key steps of the approach of the determination of the J-integral developed by Paris et al. (1977, 1979) are (i) the determination of the J-integral in terms of the system of loading and crack length while ignoring the detailed process operative within the fracture process zone near the crack tip, and (ii) crack growth (Δc) is described matching the resulting J vs. Δc relation for the system against the materials J vs Δc curve.

The elastic-plastic theory based on J-integral and tearing modulus is being developed and several attempts are being made to show how this method can be applied to study the crack growth stably and other phenomenon (Hutin, J.P. et al. 1981). Quirk and Bevitt (1987) have examined certain testing techniques specifically using 3-point and 4-point bend and centre cracked tensile specimens and have discussed the consequences of the use of the data derived therefrom in the evaluation of structural behaviour. Smith, E. (1981) has shown

how an analogous approach may be adopted for the problem of dynamic crack propagation and crack arrest with the dynamic stress intensity for the system being matched against the material's dynamic fracture toughness for various crack velocities. Some investigations related to 3-point and 4-point bend specimens have also been conducted by Braam and Prij (1986, 1987) and by Rongen (1985) in which thickness effect has also been considered. Braam, H. (1986) has made a critical study on the influence of constraint on the initiation and propagation of a crack, based on the experimental results of Rongen (1985). Braam also points out in his report that some aspects of the experimental results cannot be explained and they require further investigations.

2.3 Finite Element Method and Convergence

In most of the works referred to above finite element method or finite difference methods were adopted. Test procedures geometrical and mechanical aspects were predominant and the use of finite element method or state of convergence has not been discussed in details. Literature on these topics seems to be rare. However, Aamodt et al. (1976) have offered one of illustrative nature in describing the accuracy of the finite element method in determining the stress intensity factor for various crack lengths. Studies have been made comparing the results obtained through finite element method and available theoretical values. This study has been made particularly for the growth of cracks in welded plates-intersections subjected to cyclic loading. The finite element method has been proved to be very useful for solving many fracture problems. Various formulations of this method can be used for calculating the stress intensity factors of cracks. Of these energy release rate approach has shown to yield the most accurate results (Bergan, P. G. et al. 1974; Aamodt, B. 1974). In cases where repetitive calculations are needed Aamodt (1974) and Aamodt and others (1973) propose that super-element formulation of the finite element method is extremely economical.

The convergence properties in the presence of singularities and the determination of the stress intensity factor using conventional or special element have not been properly discussed in the existing literature. Patterson, C. (1973, 1976) while studying on the use of finite energy element energy method in calculating stress intensity factor has discussed the basic features of energy method based on the study of Oliveira, E. R. de A. (1968).

In finite element method, while developing a new element, it is generally found that approximate solution does not converge to the true solution even for quite simple problems. Oliveira has shown that if a finite element family of fields satisfy a general completeness criterion and is continuous throughout the domain of the problem, then the sequence of finite element approximate solution obtained by minimum potential energy over the finite element fields, converges in the sense of 'convergence in energy' to the exact solution whenever it is appropriately smooth. He concludes that with careful mesh selection to give adequate completeness, especially, in the neighbourhood of a crack tip, results can be obtained on test problems which are as accurate as alternative approximate methods using practicable meshes for either two or three dimensional problems. It is believed that results can reliably be obtained to acceptable engineering accuracy in many typical practical situations.

3 OBSERVATIONS

Though several attempts are being made on the investigations of the present

topic yet there are some spheres in which further investigation is expected to be performed. They are listed below :

- i) Specific test procedure, to be used for measuring fracture toughness is yet to be established.
- ii) The singularity element used to numerically characterised the near tip stress field has been successfully employed in various static applications but in comparison, the dynamic applications are rare. Attempts are to be made to fill in the gap.
- iii) Though Bretfeld, H. (1984) has investigated the detection of crack growth at an early stage with the help of acoustic emission analysis, it has not yet been (perhaps) verified whether it will be favourable for the dynamic loading too.
- iv) The failure sequence for specimen or structures containing a pre-existing crack is the onset of crack extension. The picture for a stable crack growth is yet to take a clear shape.
- v) The fundamental laws ruling the transition from slow to fast propagation and vice versa have not been clarified yet. It appears to be difficult to formulate such laws which will be applicable to both for very simple and very complicated structures. But attempts are to be made so as to extrapolate the results obtained from small specimen to the project of large and complex structures.

ACKNOWLEDGEMENT

One of the authors (M. M. Banerjee) would like to acknowledge financial assistance from Swiss Federal Institute for Reactor Research, Wurenlingen, Switzerland, to carry out this study and in particular to Professor S. K. Chakraborty and Dr. R. Wanner of the said Institute for their inspiration and keen interest in the preparation of this study.

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