Dynamic Correction Functions for K - a Numerical Approach

A. Rager, J. G. Williams, A. Ivankovic and V. Tropsa

Imperial College of Science, Technology and Medicine, Department of Mechanical Engineering, London, UK

ABSTRACT**:** *It is important to determine the fracture behaviour of polymers at impact loading and one possibility is to use a three point bend test geometry. For low and intermediate impact velocities a load based approach can be used. There are ESIS standards both for low and intermediate impact rates. Damping is recommended at intermediate velocities in the ESIS standard. For higher impact velocities (>1m/s) these load based methods are increasingly inaccurate due to dynamic effects. Therefore, in the case of instrumented high rate three point bend tests with precracked specimen the time to fracture is usually measured at high rates of loading. From the time to fracture and the compliance, a load at fracture can be computed, and subsequently K. The values for K have to be corrected to account for dynamic effects in the specimen due to inertia phenomena and stress waves. In this work these dynamic correction function is computed numerically with a finite volume procedure for strikers with different stiffness. The influence of the contact stiffness on the shape of the dynamic correction function is investigated and found to be of high importance.*

INTRODUCTION

The instrumented three point bend impact test is widely used to assess the dynamic fracture toughness of polymers. Test procedures for low [1] and intermediate (~1m/s) test velocities [2] have been developed within ESIS to standardise the impact three point bend test. However, for rates greater than 1m/s dynamic effects cause problems in evaluating toughness. Therefore it was proposed by Boehme [3] to use a dynamic correction function, a dynamic key curve (DKC), as he called it to correct the fracture toughness obtained in a quasistatic manner with

$$K_d = k_d \cdot K_{qs} \tag{1}$$

where k_d is the dynamic correction function and K_{qs} is the quasistatic fracture toughness. There are only a few ways of how to obtain this dynamic correction function. It can be measured by the use of caustics as done by Boehme [3]. One other way is to compute it numerically with the Finite Element method (FE) or the Finite Volume (FV) method. Rokach [4] has computed it with FE and found very close agreement with Boehmes measurements. However, the influence of the contact compliance on the dynamic correction function has not been investigated in numerical studies so far. Analytical research [5] showed that the contact compliance, or in other words, the compliance ratio, α, plays an important role in changing the shape of the correction curve. The compliance ratio is defined as

$$\alpha = \frac{k_1}{k_2} \tag{2}$$

where k_1 is the contact stiffness and k_2 is the specimen stiffness.

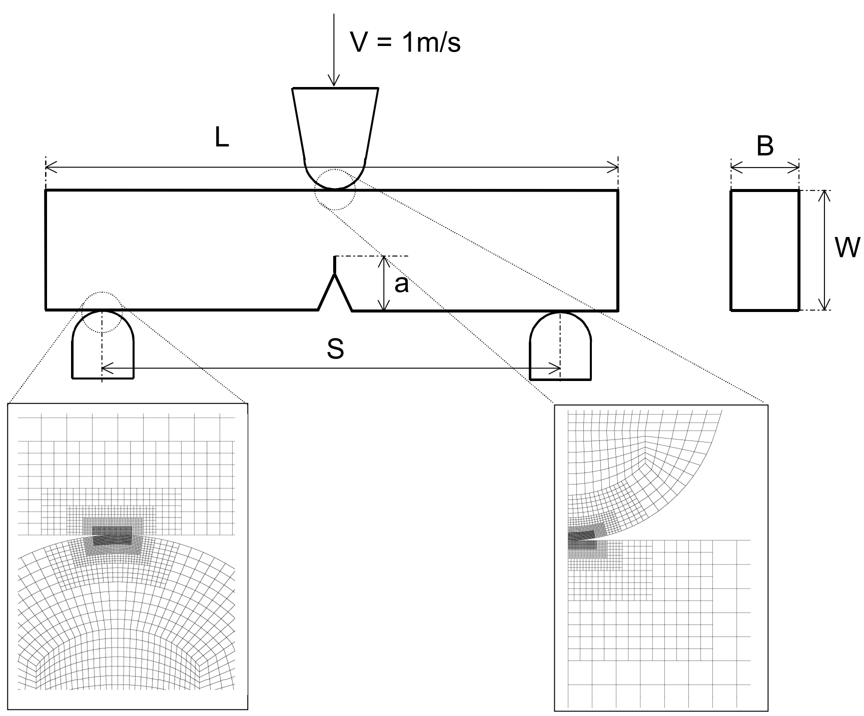

Figure 1: Specimen configuration and mesh refinement

CALCULATIONS

The calculations for this paper were calculated with the finite volume (FV) method. The FV-method is particularly suitable for dynamic, non-linear and large problems due several reasons:

- Relying on the laws of mass, momentum and energy conservation in their original integral form, the method is attractively simple, yet conservative.
- It lends itself to a segregated solution algorithm, thereby offering extremely efficient memory management, since equations are linearized and sets of equations for each dependent variable are decoupled.
- Equations are solved sequentially using an iterative solver. The technique is inherently suited for solving non-linear problems, where non-linearity arises either from material behaviour, geometry or boundary conditions.

Our numerical developments are currently incorporated within a commercial package called 'FOAM' (Field Operation And Manipulation [6]), which is a C++ library of FV discretisation routines of continuum mechanics problems. A newly developed contact procedure is used in this work, which is based on implicit, and therefore very accurate, updating of the contact parameters: i.e. contact surfaces and forces. This procedure was used for both contacts at striker and anvil.

The numerical results have been calculated for a width, W=0.1m, a span L=0.55m (L/W=5.5), the span S=0.4m (S/W=4), a notch depth of a=0.03m (a/W=0.3) and a thickness B=0.01m (Figure 1). The striker radius was 0.008m and the anvil radius was 0.01m. These values were taken from [7] for a comparison with measurements from caustics. Mechanical properties of epoxy (Araldite B) were used for the specimen. A constant displacement of 1m/s was applied on the top of the striker. Only half of the specimen had to be modelled for symmetry reasons. A locally refined FV mesh (Figure 1) with 25875 cells was generated. Five levels of refinement on the specimen side and four levels on the striker/anvil side were used to have a sufficient amount of similar sized cells in contact. At an average load there were around 20 cells in contact at the striker/specimen contact and around 10 cells for the specimen/anvil contact.

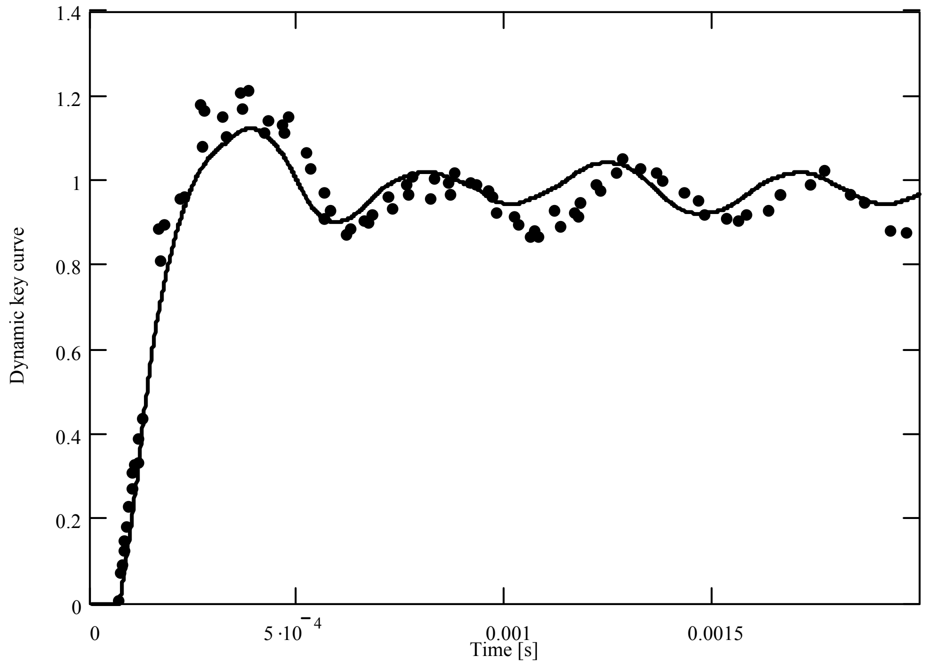

Figure 2: Comparison of the numerical dynamic correction function for steel striker and steel anvil with measurements from [7]

Two cases were calculated to highlight the influence of the contact stiffness:

- High contact stiffness (steel striker)
- Low contact stiffness (PE striker)

In both cases the anvil was modelled as steel, whereas in the experiment epoxy was used as an anvil.

RESULTS AND DISCUSSION

As it can be seen in Figure 2 the combination steel for the anvil and steel for the striker yields results quite close to the experiments, where an anvil made of EP was used. Only at longer times greater than 1ms the results start to differ from the experiment. This is obviously due to the influence of the anvils, which are having higher stiffness in the simulation than in the experiment. For short times (less than 0.5ms in the diagrams), which are of the biggest practical importance, the stress waves coming back from the anvils have not reached the crack tip yet. From other computations it was observed that the anvils have an impact on the curve only after around 0.5ms for this specimen geometry.

In Figure 3 the numerical results of a simulation with the properties of PE being used for the striker are shown. Apparently the shape of the curve is very different. The loading of the crack tip is much slower as in the case with a steel striker. This is due to the influence of the contact compliance, which is much lower in this case. From analytical studies [5] it is known that the contact compliance is playing a very important role in controlling the shape of the dynamic key curve. This can clearly be seen to be the case for the numerical results as well.

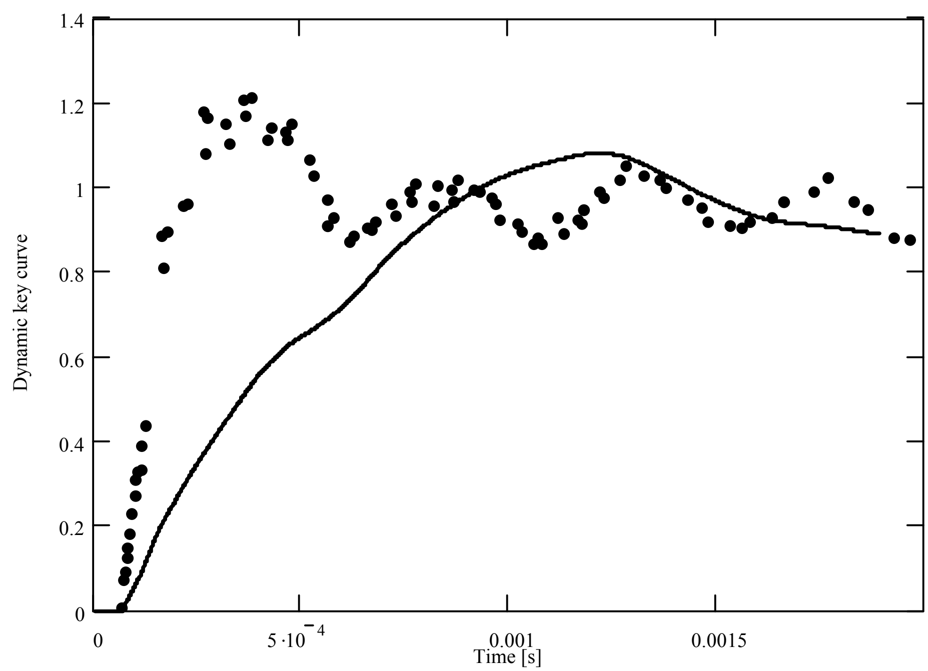

Figure 3: Comparison of the numerical dynamic correction function for PE striker and steel anvil with measurements from [7]

CONCLUSIONS

The results presented in this paper show that the dynamic key curve is not unique for all contact stiffness ratios, but varies with this parameter. The argument found in the literature was that the dynamic correction function could be determined with one setup with similar proportions and could be linearly scaled down for any specimen size. From this work it is now found that in case of a low contact stiffness, e.g. damping used or a deformable striker, the dynamic correction function will considerably change and will need to be determined individually. Further work is in progress to clarify this issue.

REFERENCES

1. ESIS TC4 (1990). Testing Protocol. A Linear Elastic Fracture Mechanics Standard for Determining Kc and Gc for Plastics.
2. ESIS TC4 (1997). Testing Protocol. A Linear Elastic Fracture Mechanics Standard for Determining Kc and Gc for Plastics at High Loading Rates.
3. Boehme, W. (1995). In: *Impact and Dynamic Fracture of Polymers and Composites*, pp. 59-71, Williams, J.G. and Pavan, A. (Ed.). Mechanical Engineeting Publications, London.
4. Rokach, I. V. (2000) In: *Proceedings ECF 13*. San Sebastian, Spain.
5. Williams, J. G., Tropsa, V., MacGillivray, H., Rager, A. (2001) *International Journal of Fracture* **107**, 3.
6. www.nabla.co.uk
7. Boehme, W. (1985) PhD Thesis, TH Darmstadt, Germany.