# PRACTICAL PROCEDURE FOR DYNAMIC STRESS INTENSITY FACTOR HISTORY DETERMINATION IN INSTRUMENTED IMPACT TESTING

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Two versions of simple procedure are presented for processing the load-time records registered during instrumented impact testing of pre-cracked specimens. Time variation of dynamic stress intensity factor (DSIF) is calculated using the numerically determined specimen impact response. An example of one-point-bend test data processing is given.

## INTRODUCTION

When the dynamic fracture toughness of sufficiently brittle material is determined by means of the instrumented impact testing, the time-to-fracture is often less than $3\tau_1$ . Similar situation is distinctive to one-point (unsupported) bend testing conditions. In both cases the commonly used quasistatic methods for the force-time diagrams processing are insufficient. High accuracy is inherent to results obtained by full scale dynamic finite element simulation of cracked specimen behaviour during testing, but these calculations are too expensive. In this paper two versions of a simpler approach are considered. It permits to obtain $K_I(t)$ with sufficient accuracy using only pocket or desktop computer.

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## THE METHOD PROPOSED

Consider, for simplicity, one-point-bend testing conditions. If we know DSIF for unit midspan impulse loading - specimen impact DSIF response $h_K^{(1)}(t)$, then for arbitrary force F(t) acting on rest before testing specimen

$$K_I(t) = \int_0^t F(\tau) h_k^{(1)}(t-\tau)d\tau . \qquad (1)$$

In the works by Kishimoto et al (1-3) impact response functions used in equation (1) were obtained for beam models of specimen. Simulation of three-point-bend testing conditions were carried out in assumption that specimen is in permanent contact with the anvils. More precisely specimen-anvils interaction (including its possible separation observed by Böhme and Kalthoff (4)) may be modelled when two equal forces of the anvils reactions R(t) are introduced (Fig.1). These forces should be experimentally measured together with F(t). Similarly to equation (1) for this case we shall obtain

$$K_I(t) = \int_0^t F(\tau) h_k^{(1)}(t-\tau)d\tau + \int_0^t R(\tau) h_k^{(2)}(t-\tau)d\tau . \qquad (2)$$

We may obtain from (1) and (2) different formulae for $K_I(t)$ calculation using different approximation methods for F(t) and R(t). Two such methods are briefly considered below for one-point-bend testing conditions (the similar formulae for three-point bending can be found in author's works (5,6)).

### The 1st version: piecewise linear approximation

Let us approximate F(t) by N-section broken line (this operation is generally accepted when treating the oscillograms recorded in the form of phorographs):

$$F(t) \approx \sum_{i=1}^{N} (c_i - c_{i-1})(t - t_{i-1})H(t - t_{i-1}) . \qquad (3)$$

Substituting relation (2) into formula (1) we shall obtain

$$K_I(t) \approx \sum_{i=1}^{N} (c_i - c_{i-1}) \hat{h}_k^{(1)}(t - t_{i-1}) \qquad (4)$$

where

$$\hat{h}_k^{(1)}(t) = H(t) \int_0^t \tau h_K^{(1)}(t-\tau)d\tau .$$

For $\hat{h}_K^{(1)}(t)$ a simple approximating expression was obtained (see details in (7))

$$\hat{h}_k^{(1)}(t) \approx k_{Is}^{(1)}(t)(t - \sum_{i=1}^{n} (\eta_i / \omega_i) \, Sin(\omega_i t). \qquad (5)$$

## The 2nd version: Fourier series approximation

Let the force acting upon the specimen in the time interval $[0,T]$ be approximated by a part of its Fourier series

$$F(t) \approx \sum_{k=0}^{m} (a_k Cos(kpt) + b_k Sin(kpt)). \qquad (6)$$

This procedure is generally employed for analysis and storing in compact form of the experimental force-time diagrams recording using digital registrating equipment.

Differentiating twice the approximation of the function $\hat{h}_k^{(1)}(t)$ (equation (5)) one can obtain the expression for the specimen impact DSIF response

$$h_k^{(1)} \approx k_{Is}^{(1)} \sum_{i=1}^{n} (\eta_i \omega_i \, Sin(\omega_i t)). \qquad (7)$$

Substituting formulae (6) and (7) into relation (1) we shall finally obtain

$$K_I(t) \approx k_{Is}^{(1)} \sum_{i=1}^{n} (A_i Cos(\omega_i t) + B_i Sin(\omega_i t) + \sum_{k=0}^{m} ((a_k Cos(kpt) + b_k Sin(kpt))/(1 - k^2 (p/\omega_i)^2)) \qquad (8)$$

where

$$A_i = - \sum_{k=0}^{m} (a_k / (1 - k^2 (p/\omega_i)^2))$$
$$B_i = -(p/\omega_i) \sum_{k=1}^{m} (k b_k / (1 - k^2 (p/\omega_i)^2)) \qquad (9)$$

## CALCULATIONS

The values of parameters $k_{IS}^{(1)}$, $\eta_i$, $\omega_i$ (i=1-3) and their analogues for anvil reaction forces were determined from two dimensional (plane stress) finite element analyses of specimen. Numerical results obtained for L/W = 2.0 ... 6.0, a/W = 0.3 ... 0.7, $\mu$= 0.2 ... 0.4 were either polynomially fitted ((5),(7)) or used for table interpolation in appropriate programs for $K_I(t)$ calculation.

## AN EXAMPLE OF EXPERIMENTAL DATA PROCESSING

To aprobate the suggested approach the results of one-point-bend test reported in (4) were used. The Araldite B specimen dimensions were: L=0.412, W = 0.1, B = 0.01, a = 0.03. Experimentally $K_I(t)$ was determined by the shadow method of caustics. The DSIF-time variations calculated using both methods of F(t) approximation gave practically the same result which agrees sufficiently with the experimental one (Fig.3).

## SYMBOLS USED

| | | |
|---|---|---|
| $a_k, b_k$ | = Fourier series coefficients | (N) |
| $c_i$ | = the slopes of broken line sections ($C_0$ =0) | (N/s) |
| F(t) | = tup force | (N) |
| H(t) | = Heaviside function | |
| $h_k^{(1)}(t)$ | = specimen DSIF response for unit impulse of tup force | ($m^{-3/2} \cdot s^{-1}$) |
| $h_k^{(2)}(t)$ | = specimen DSIF response for two unit synchronized impulses of anvils forces | ($m^{-3/2} \cdot s^{-1}$) |
| $\hat{h}_k^{(1)}(t)$ | = specimen DSIF response for unit slope increasing tup force | ($s/m^{-3/2}$) |
| $k_{Is}^{(1)}$ | = SIF for specimen loaded according to one-point static bending mode (Fig.2) per value of uniformly distributed volume forces | ($m^{-3/2}$) |
| m | = number of harmonics in Fourier series expansion of the tup force | |
| N | = number of broken line sections | |
| n | = number of specimen free vibration modes which was taken into consideration | |
| p | = $2\pi/T$ | (rad/s) |
| R(t) | = anvil force | (N) |
| $t_i$ | = abscissae of the nodal points of broken line ($t_0$ =0) | (s) |
| $\mu$ | = Poisson's ratio | |
| $\eta_i$ | = weight coefficients determining the contribution of each natural mode into the process of specimen transient vibrations | |
| $\tau_1$ | = $2\pi/\omega_1$ period of main mode of the specimen vibration | (s) |
| $\omega_i$ | = angular natural frequencies of the specimen (symmetrical modes) | (rad/s) |

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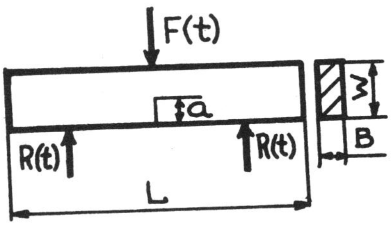


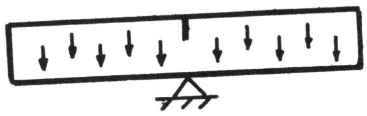

Figure 1 Test specimen

Figure 2

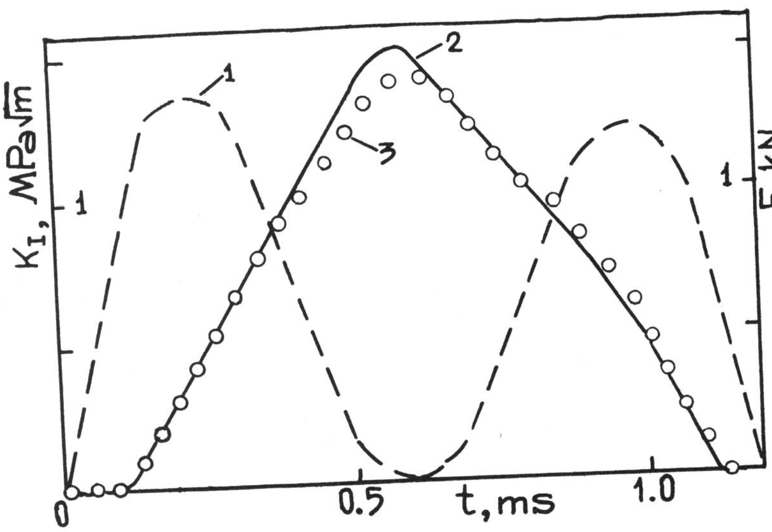


Figure 3 Loading history (1) and DSIF variation in time obtained experimentally (2) and numerically (3)