TO THE QUESTION OF EVALUATION OF CRACK GROWTH RESISTANCE OF STRUCTURAL MATERIALS UNDER DYNAMIC LOADING

V.V Panasyuk*, O.E. Andreykiv*, Z.T. Nazarchuk*, S. Ye.Kovchyk*
and I.V.Khodan*

The purpose of this paper is to present a new numerical experimental procedure, which allows determination of dynamic stress intensity factor (DSIF) of materials at high loading rates. The proposed approach allows to take into account the inertial effect, provides necessary accuracy and short time necessary for calculations. Basing on theoretical investigations, which are both uncomplicated and precise the simple relationship for specimens are presented. The experimental verification of the determination DSIF during one- and three-point bending of the beam is successfully results confirmed.

INTRODUCTION

For determination of dynamic stress intensity factor we estimate not only its critical value, but also its full dependence on the history of its change for loading time, bearing in mind, that the constant growth rate of $K_I(t)$ is a control parameter of the experiment. The available in literature arbitrary identification of the variation character with a similar character of dynamic loading F(t) variation causes the significant errors in evaluation of the experimental data while existing corrections to F(t) include only the inertial component without taking account of the influence of variation in a "specimen-machine" system. This processed cause noticeable oscillations of dependence F(t), which complicate its interpretation within the scope of quasistatic approach.According to ASTM recomendations this approach can be used in tests when the time to crack initiation is at least threefold greater than the maximum period of the natural oscillations.However, this requirement oftenly is not fulfild in the case of brittle materials (1) and is insufficient at high loading rates.

* Karpenko Physico-Mechanical Institute of the Academy of Sciences of Ukraine, Lviv, Ukraine

The K_I (t) dependence can be obtained experimentally - either in terms of the value of the short-length signal (Fig.1a), fixed at the crack tip (2) or using method of photoelasticity or the shaded stains method (caustic) (3) in combination with high-speed photography. The application of this method is most sensible in standard experiments. The models of basic solutions for evaluation of K_I (t) in a compact analytical form on the basis of the linear fracture mechanics dynamic problems solution are proposed in the paper,which continue the researches presented in (4).

CALCULATION OF FRACTURE PARAMETERS

Having determined the load-time test, various fracture parameters can be calculated. Our procedures are based on the beam specimen bending.The experimental data evaluation is based on the analytical results on dynamic stress intesity factor determination during one-point and a beam specimen three - point bend test. Dynamic loading time F(t) is defined by Fourier series:

$$F(t) = \frac{a_0}{2} + \sum_{k=1}^{m} [a_k \cos kpt + b_k \sin kpt] \qquad (1)$$

where $p = 2\pi / T, T$ - loading time.

In the case of one - point bending (Fig. 1) the DSIF is determined from equation (2)

$$K_I(t) = K_{IS}^{(1)} \sum_{i=1}^{N} \eta \{ A_i \sin(\omega_i t) + B_i \cos(\omega_i t) +$$

$$+ \frac{a_0}{2} + \sum_{k=1}^{m} \frac{1}{1-(kp/\omega_i)^2} [a_k \cos kpt + b_k \sin kpt] \Bigg\}, \qquad (2)$$

$$A_i = - \frac{\rho}{\omega_i} \sum_{k=1}^{m} \frac{kb_k}{1-(kp/\omega_i)^2}, \quad B_i = - \frac{a_0}{2} - \sum_{k=1}^{m} \frac{a_k}{1-(kp/\omega_i)^2}. \qquad (3)$$

where $K_{IS}^{(1)}$ - stress intensity factor of a uniformally loaded beam specimen in one-point bending tests, ω - angular frequencies of symmetric waves during one - point tests of precracked specimen, N - number of modes, η_i - weight coefficients, indicating each mode contribution, ρ - material density, E - Young's modulus.

For $0.3 \le \lambda \le 0.7,\ 2 \le \gamma \le 6\ (\lambda = l/W,\ \gamma = L/W)$.

$$\omega_1^* = -0.336 + 0.806\lambda - 0.481\lambda^3 + (3.01 - 5.22\lambda + 2.23\lambda^2), (3\%),$$

$$\omega_1^* = \omega_1 W\sqrt{\rho / E} \tag{4}$$

$$K_{IS}^{(1)} = L\sqrt{l}\, Y^{(1)}(\lambda,\gamma)/BW^2, \tag{5}$$

$$Y^1(\lambda,\gamma) = -0.188 - 0.924/\gamma + 12.2\lambda - 30.8\lambda^2 + 30.0\lambda^3,$$

$$\eta_1 = 0.358 + 1.36\lambda - 0.654\lambda^2 + (1.78 - 3.49\lambda + 1.42\lambda^2)/\gamma, (2\%), \tag{6}$$

$\omega_2, \omega_3, \eta_2$ and η_3 is presented in (4).The interpretation of the components of equation (2) is given by relationships (1), (3)-(6). The equation for $K_I(t)$ evaluation (2) is verified by Giovanola I. (2) experiment, using steel specimens. In this case the $K_I(t)$ value was experimentally determined, using calibrated strain gauge under static loading. The moment of crack initiation was determined by a specific signal of loading drop. Fig. 1b presents the approximation of the loading history. Basing on this approximation and equations (2)-(6), we have obtained the calculational dependence which is in good agreement with the experimental results (Fig.1c).

In the case of three-point bending (Fig.2a) dynamic R(t) is defined by Fourier series:

$$R(t) = \frac{a_0^{(2)}}{2} + \sum_{k=1}^{m} [a_k^{(2)} \cos kpt + b_k^{(2)} \sin kpt], \tag{7}$$

For evaluation of DSIF the equation (8) has been obtained:

$$K_I(t) = \mathbf{K}_{IS}^{(1)} \sum_{i=1}^{N} \eta_1 \{ A_i^{(1)} \sin(\omega_i t) + B_i^{(1)} \cos(\omega_i t) +$$

$$+ \frac{a_0^{(1)}}{2} + \sum_{k=1}^{n} \frac{1}{1-(kp/\omega_i)^2} \left[a_k^{(1)} \cos kpt + b_k^{(1)} \sin kpt \right] \} + \tag{8}$$

$$(\mathbf{K}_{IS}^{(3)} - \mathbf{K}_{IS}^{(1)}) \sum_{i=1}^{N} \eta_1 \{ A_i^{(2)} \sin(\omega_i t) + B_i^{(2)} \cos(\omega_i t) +$$

$$+ \frac{a_0^{(2)}}{2} + \sum_{k=1}^{m} \frac{1}{1-(kp/\omega_i)^2} \left[a_k^{(2)} \cos kpt + b_k^{(2)} \sin kpt \right] \},$$

$$A_i^{(j)} = - \frac{\rho}{\omega_i} \sum_{k=1}^{m} \frac{kb_k^{(1)}}{1-(kp/\omega_i)^2}, \quad B_i^{(j)} = - \frac{a_0}{2} - \sum_{k=1}^{m} \frac{a_k^{(j)}}{1-(kp/\omega_i)^2},$$

$j=1,2$; $K_{IS}^{(3)}$ - stress intensity factor for a beam specimen three - point bending test. The equations, similar to that in one-point bending were obtained for values η_i, ω_i, $\mathbf{K}_{IS}^{(3)}$ presented in (5). In the Fig.2 the similar approach for three - point bending, taking into account the specimen interaction with the bases R(t) is presented. Equation (7) has been proves by experimental data obtained in large scale specimens testing (6). The approximated dependencies F(t) and R(t) are given in Fig. 2a,b. Basing on these dependencies we calculated the DSIF values. So, for plotting of the K (t) dependence, it is necessary to have the written fracture curve and typical specimen sizes. Comparison of the experimental and calculated data is presented in Fig. 2c.

REFERENCES

(1) Server, W.L. "Charpy impact testing ", Amer. Soc. Metals, vol. 8 , 1985, pp. 261-268.

(2) Giovaniola, J.H., "Fracture Mechanics", ASTM STP 905, Philadelphia, vol. 17, 1986, pp. 307-328.

(3) Bohme, W. and Kalthoff, J.F., Int. J. Fract.., vol. 20, ¹ 4, 1982, pp. 139-143.

(4) Andreykiv, A.E. and Rokach, I.V., Physics-chemical Mechanics of Materials, 15, 1989, pp. 42-51.

(5) Srawley, J.E., Int. J. Fract., vol. 12, ¹ 3, 1976, pp. 475-476.

(6) Bohme, W., "Experimentelle Untersuchungen dynamischer effecte beim Kerbschlagbiegeversuch", Frauenhofer Inst. Fur Werkstoffmechanik, Darmstadt, 1985, 126S.

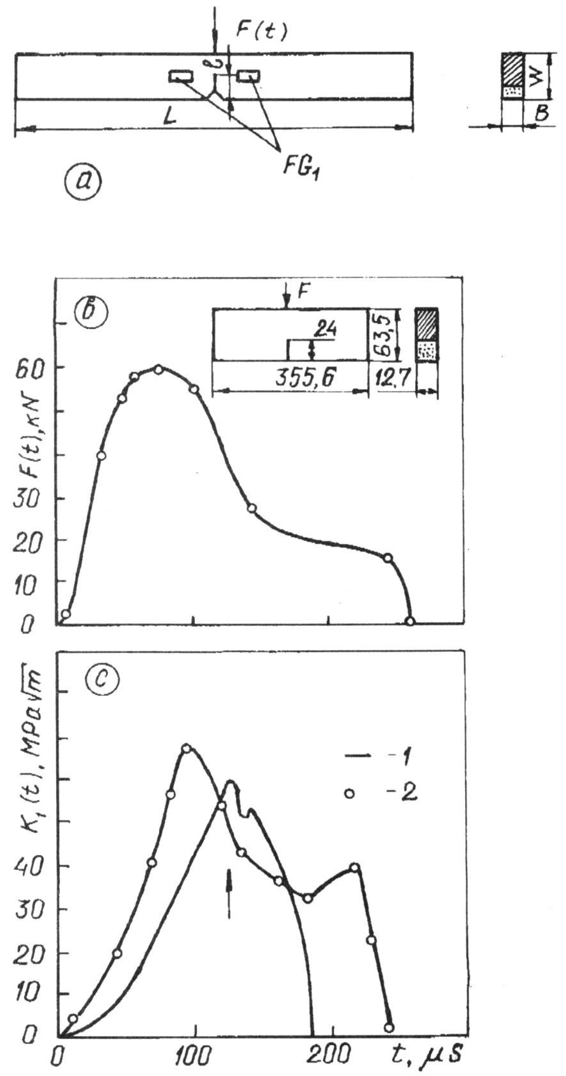

Figure 1 Evaluation of the method of DSIF for a beam specimen one-point bending tests: 1 - experimental data (2); 2 - calculation data

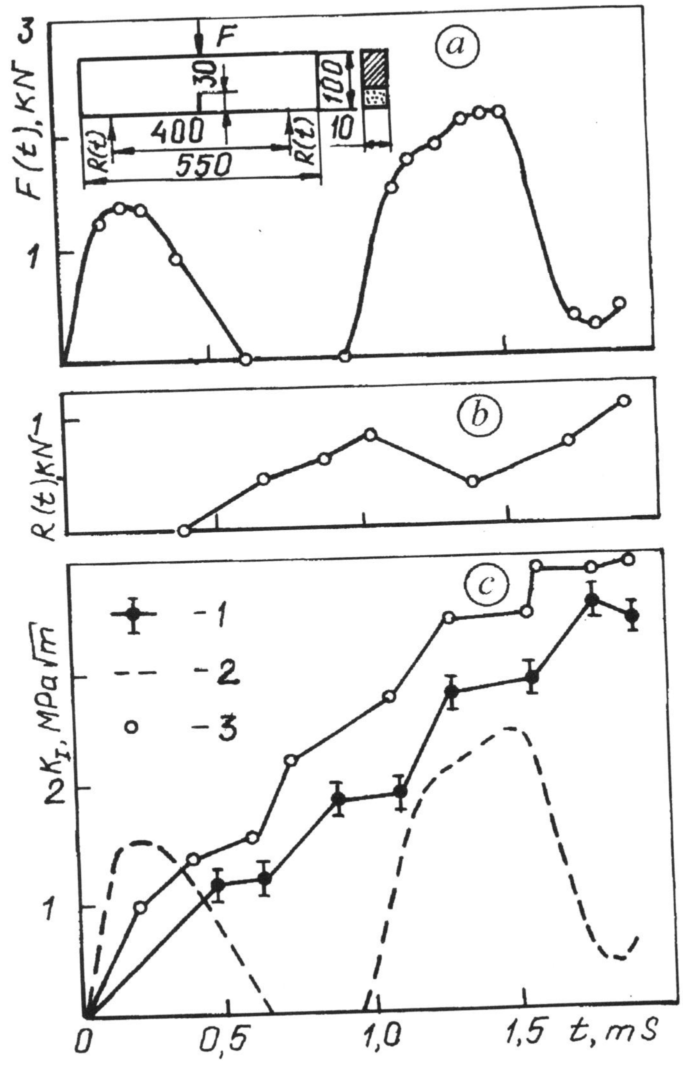

Figure 2 Evaluation of the method of DSIF determination for a three-point bending test: 1 - experimental data (6); 2 - quasistatic; 3 - calculation data