COMBINED LOADING MODE:
THE BRITTLE FRACTURE MECHANISM ANALYSIS..

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Abstract: The investigation of reaction of the static-dynamical loading (pulse hit action of the striker to a notch of the previously rigidly loaded single-edge-notched specimen) of the model polymer material in wide temperature range from –90°C to 20°C was carried out. On the base of the dependence of stress and deformation tensors components distribution from the velocity of fracture propagation, the energy criterion of the fracture toughness is propose, as the modulus of the energy flow into the fracture tip. The fractographic investigations of the fracture surface of the specimens by the electron scanning microscopy methods have been made. The sizes of characteristic zones are detected, competent for the different levels of structural destruction. The critical parameters of fracture have been determinate.

1. INTRODUCTION

Experimental researches on statico-dynamical loading were carried out on model installation «MID-1». The principle of an operation of installation is based on a system of a synchronization of pilot signals is magnetic - impulse of the loading system with a high-speed camera [1].

For want of it the sample were in conditions of static expansion, is subjected wedging impact on a edge notch (loading so-called “running crack”). The scheme of loading is indicated on Fig.1. In experiment samples with one-edge-notch for want of fixed loads were tested in the field of elastic proportionality of a model material polymethyl metacrylate (PMMA) for want of following temperatures of tests: -90° degrees of Celcius, -40° and + 20° degrees.

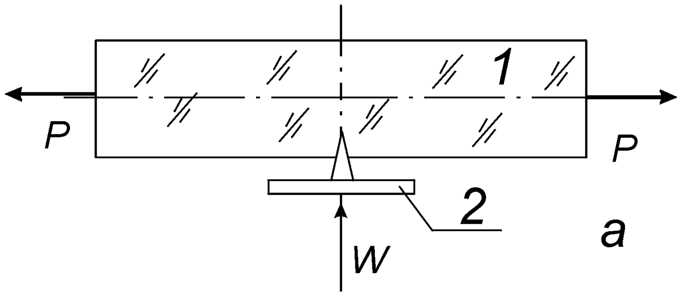

Fig. 1 The scheme of loading

The tested sample represents a flat plate of the rectangular form from an organic glass (PMMA - polymethyl metacrylate) with the artificial concentrator of stresses as a triangular excision on one from the parties. The geometric sizes of a sample are selected so that to satisfy to conditions of a flat strain. The sample were in the camera at the temperature of T, °C, is stretched up to the certain magnitude of a force P, N (within the limits of elastic proportionality), then is rigidly fixed. At the moment of impact on a notch special with striker’s energy W_S (J), which initializes crack formation, the signal on a high-speed camera recording process of a crack growth moves. The velocity of a crack was determined from the coordinate of its tip, measured on negatives, and calculated time of registration of each frame. The outcomes of calculations for seven fixed levels of a load (magnitudes of energy of capacitors) are shown in table 1.

Table 1. MID-1 installation parameters

Capacitors energy		Striker velocity V_S, m/s	Max. energy of striker's pressure W_S, J
Capacitor C_i	W_c, J		
C_1	*192*	*3*	*5,65*
C_2	*256*	*5*	*17,3*
C_3	*356*	*6*	*35,3*
$C_{1,2}$	*448*	*12*	*45,0*
$C_{2,3}$	*547*	*13*	*79,4*
$C_{1,3}$	*611*	*14*	*86,4*
$C_{1,2,3}$	*803*	*20*	*135,0*

2. DETERMINATION OF AN ENERGY CRITERION

In order to decide the problem about a determination of an energy criterion of fracture toughness we have emanated from the following premises:

1. Considered a flat problem of the theory of an elasticity.
2. Have decided a problem of a dynamic mechanics about a driven crack, i.e. in an instant time (t = 0), velocity (v > 0_;

Basic data for a solution of such problem are a velocity and the length of a crack at the moment of registration. The in this case acceptable candidate solution is the method developed by Sher based on Irvin's work and Kregg's solution for a problem about stationary distribution of a slit, etc. [2]. The given method is based on the known supposition that in a neighbourhood of top of an arbitrary driven crack of stress have a feature of the order $r^{-1/2}$, where r – distance from top of a crack, which is fair for static cases, but also is distributed to dynamics. With allowance for about the given feature find angular distribution of stresses around the tip of a driven crack. The problem is decided in two stages:

1). Determination of Stress intensity factor.

2). Definition of a trajectory of a crack propagation (in our case, actually rectilinear).

The deformed condition at the tip of a crack here is determined because of solutions of the following problem:

$$l(t) = \mathrm{v}t;\quad \vec{\mathrm{u}} = \vec{\mathrm{u}}(x_1 - \mathrm{v}t, x_2);\qquad \mathrm{v} = \mathrm{v}(t) = \mathrm{d}l/\mathrm{d}t \tag{1}$$

Where $x_1 = l(t)$ - coordinate of the right edge of a crack, located on the axes x_1 ($x_1 < l$)

Designating $x_1 - \mathrm{v}t = x;\ \ x_2 < x < x_1$, from a solution of the equation of dynamics of the linearly – elastic body, we receive expression for significance of components of a stress tensor σ_{22}. In that specific case of rectilinear propagation of a crack along an axes x it is possible to note [1]:

$$\sigma_{22} = \frac{3}{4\sqrt{x}}\mu\alpha\left[-(1+\beta) + \frac{4\sqrt{\alpha\beta}}{(1+\beta)}\right] \tag{2}$$

Where, $a = 1 - \dfrac{\mathrm{v}^2}{\mathrm{c}_1^2}$, $b = 1 - \dfrac{\mathrm{v}^2}{\mathrm{c}_2^2}$,

Thus, the flow of energy in a crack tip can be expressed by a following relationship:

$$G(\mathrm{v}) = \frac{1}{\pi\mu}\left[-\frac{(1-\beta)\sqrt{\alpha}N_{22}^2}{(1+\beta) - 4\sqrt{\alpha\beta}}\right] \tag{3}$$

Where $N = \sigma_{22} p \sqrt{x}$. The expression (3) in essence is a Griffit's energy criterion of destruction at $v \to 0$.

The parameters μ, c_1 and c_2 were obtained from experimental data on expansion of flat smooth slices from PMMA (see tab. 2).

Table 2. Mechanical properties and elastic characteristics of PMMA

E, kg/m^2	μ, kg/m^2	ν	c_1, m/s	c_2, m/s	ρ, kg/m^3
3,613 • 10^9	1,411 • 10^9	0,28	2290	1322	1125

Proceeding from which, by a substitution of obtained significances of stresses from (2) the numerical significances for a flow of energy into a crack tip can be obtained depending on a velocity of propagation.

Basic magnitude here is the significance of a stream of energy acting(arriving) at top of a driven crack. The series of discrete data's of significances G can be presented as a modification of energy of a strain come per unit of a new surface of destruction, by input ΔG - differences of two adjacent significances of an energy flow.

For want of it the developed empirical dependence, approximating experimental data for statico-dynamic loading of the following kind [1] was used:

$$x = a * (273{,}16 - T) * t^{b(1+P)} * \exp\left(-c\frac{1+P}{W_s}t\right) \quad (4)$$

A following pitch is the adaptation of an empirical model of development of a crack to a determination of an energy flow into the tip of a crack. As an initial critical parameter is selected critical length of a crack, defined from fractographic researches of surfaces of a fracture under effect of statico-dynamical loading.

At want of research fractograms of surfaces of destruction is exemplar, by means of a raster microscopy it was revealed, that the surfaces of destruction have three kinds of sequential zones: mirror, dim, pen. Agrees, [3] extremities of a mirror zone of destruction correspond to work to the beginning of brittle destruction of polymers.

Therefore, in our case critical length of a crack is determined as the sum, initial length of a cut of a polymeric sample with ОБН and expansion of a mirror zone of destruction:

$$l^*_{\text{тр}} = l_0 + l_{\text{зер}}; \quad (5)$$

Being based on experimental data and data's of empirical dependence, for want of a crack propagation we can define following three interdependent parameters: x - coordinate of a crack tip, V - growth rate of a crack and σ_{22} - generalized stress of the acting combined statico-dynamic load. The use further of significances (2), (4) and (5) with allowance for of fractography data's in expression (3) allows to receive value's of an energy flow acting to the tip of a driven crack. Dimensionality of a flow of energy J/m^2.

Table 3. Critical parameters of the PMMA in dependence from temperature at W_S=135 J, P=981 N

Temperature, °C	-90	-40	20
Critical value as the module of an energy flow, J/m^2	1,59•10^4	1,581•10^5	1,4•10^6

3. FRACTOGRAPHIC INVESTIGATIONS OF THE FRACTURE SURFACE

For want of fractogramm's research of surfaces of destruction is exemplar, by means of a raster microscopy it was revealed, that the surfaces of destruction have three kinds of sequential zones:

- Mirror;
- Dim;
- Pen;

The first zone, is characterized by traces as grooves on a smooth surface, which are orthogonal to front of promoting of a crack. The given zone corresponds initial, slow, stage of distribution of a crack. The experimental data have shown, that with magnification of energy of impact is brisk, the expansion of the given zone decreases.

In the first zone the rupture of connections happens in a crack tip, i.e. in the field of overstressings, which are characteristic irrespective of, through what elements by molecular or overmolecular of a structure there passes it top. The probability of a rupture in this area is more, than in other places of a sample, as this probability is determined by not average stress in a sample s, and local stress in a crack tip.

The second zone with traces as «parabolas» or «hyperbolas» and tearing lines, corresponds more to high levels of energies and velocities of a crack propagation.

It is visible, that in a focal point of each parabolic figure there is a microconcavity, from which the secondary destruction, size of the order 1 - 10 microns originates. The data's sizes are comparable to sizes of an overmolecular structure of a polymethyl metacrylate. The sizes of clusters, which, also lie within the limits of 1-10 micrometer..

And, it is necessary to notice, that the distribution of secondary microcracks from structural defects - intercluster boundaries, on the second stage has independent, casual character.

Third, pen, zone on a surface of destruction answers the third stage of distribution of a crack from a constant by an average velocity and is characterized by a contour as "scaly". Between the second and third zones on a surface of destruction the rather sharp boundary is observed.

4. CONCLUSION

As well as it was necessary to expect, the least flow of energy of a crack, acting at the tip, corresponds to case of destruction of a sample for want of –90°C. Other two cases on a pioneering stage of destruction are identical (sizes « mirror » of zones are comparable), it is necessary to consider, that at the given stage a prevailing role plays wedging effect. Further in case + 20°C the destruction is possible is supported at the expense of accumulated elastic energy of a strain. In table 3 the obtained critical significances of the module of a stream of energy for datas of experiments are represented.

5.ACKNOWLEDGEMENTS

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