CRACK SPREADING IN VISCOELASTIC BODIES WITH ACCOUNT OF AGEING MATERIAL PECULIARITIES

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ABSTRACT

The model representation of the fracture process in ageing **viscoelastic body with the** crack is based on the choice of the rheological material model,on the description of the crack model and on the fracture criterion which is connected with the crack initiation. For the description of the rheological peculiarities of the natural ageing materials Arutyunyan's (1952)hereditary theory of ageing was chosen and it was grounded by the experiments. From the criteria of COD and Knauss (1970) the equations of the crack growth in viscoelastic materials subjected to aging were obtained.

KEYWORDS

Ageing,crack,fracture,criterion COD,Knauss criterion.

<u>The Rheological Model of the Material.</u> For the **description** of the stress in deformation condition of the ageing viscoelastic body we use Arutyunyan (1952) hereditary theory of ageing. The main system of this theory equations differs from the system equations of the theory of hereditary non-ageing bodies by only the group of equations which establish the dependence between the stress and deformations with time,i.e. rheological equations.In the hereditary theory of ageing we use the integral operators with the kernels of non-deference type. In this theory the rheological equations may be expressed in the form

$$
\begin{aligned}
s_{ik}(t)&=2G_* l_{ik}(t),\\
\sigma_{ii}(t)&=3K_* \varepsilon_{ii}(t),
\end{aligned}
\qquad (1)
$$

where G_* and K_* are the linear integral operators of the form

$$K_* \varepsilon_{ii}(t)=K(t)\, \varepsilon_{ii}(t) + \int_{t_1}^{t} K(t,\tau)\, \varepsilon_{ii}(\tau)\, d\tau, \qquad (2)$$

and $K(t,\tau)$ is the creep kernel of ageing viscoelastic material. Usually,the creep kernel $K(t,\tau)$ in the equation (2) can be written in the form

$$K(t,\tau)= - \frac{\partial}{\partial\tau} \left[\frac{1}{E(\tau)} + C(t,\tau) \right] , \qquad (3)$$

where $E(\tau)$is the modulus of elastically current deformation and $C(t,\tau)$ is the measure of creep in ageing material. The measure of creep $C(t,\tau)$ in this theory can be written in the form

$$C(t,\tau)= \varphi(\tau)\ f(t-\tau)\ , \qquad (4)$$

where $\varphi(\tau)$ is the function of ageing material, and $f(t-\tau)$ is its hereditary qualities.

This theory can be used for the most wide-spread ageing mate--rial in the industry, for example, for the concrete. The author didn't know about the experimental control of the theory of hereditary ageing for polymers and composites on their base. So the experiment was carried out in order to investigate the influence of natural ageing on the characteristics of rigidity and long-term crack resistace of the triacetate film of 4 ages (3,8,16,23).

The influnce of ageing on the characteristics of rigidity. The limit change of rigidity σ_b and limit deformation under the tension ε_p were investigated on the set of showel samples (6 samples in each set), the dimensions 250x15x0.18 mm, the working part 170 mm. The analysis of the obtained results showed that the limit rigidity of the triacetate film increased steadily with the age and for 20 years it increased approximately by 25%. The limit deformations ε_p, obtained for the triacetate film decreased by 60,3% for 20 years. The decrease of ε_p under natural conditions of ageing for polymers and composites on their base was marked by a great number of investigations. The investigation of Youngs modulus for the triacetate film showed that E inereases steadily with the age and comes nearer to its limit meaning E_∞, in the old age. In the given investigation it was established that Youngs modulus E for 20 years increased by 22%. For the description of the dependence of Youngs modulus from time we use (Arutyunyan 1952) equation

$$E(\tau)=E_\infty \left[1-\ \beta\ \exp(-\alpha\tau)\right], \qquad (5)$$

where τ is the age of the material, E_∞ , β, α - are the constants. For the triacetate film the meanings of the constants in formula (5) are the following β=0,16, α=0,03 and E_∞ equals Youngs modulus at the age τ=23 years E_∞ =5456 MPa. The maximum declination of the experimental data from the meanings in formula (5) doesn't exceed 3%. The creep of the triacetate film was investigated on the plain samples 298x25x0,18 mm. The creep locus for four ages are shown in Fig.1.

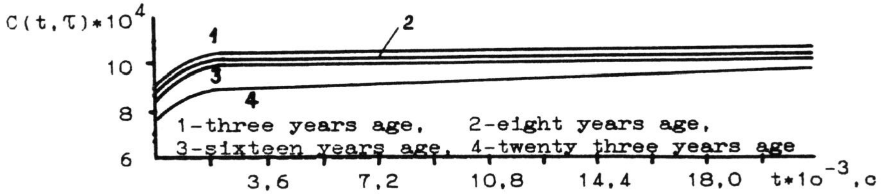


Fig.1

From the analysis of the creep locus it follows that the material in the young age has more deformation than in the old age. The qualitative change of the creep deformation coordinates with the results of the tests on the creep of concrete by Arutyanyan (1952). The obtained experimental locus are described by the degree of creep $C(t,\tau)$ in the (Zevin,1973)

$$C(t,\tau)=\left[C+A\exp(-\mu\tau)\right] \int_\tau^t \mathrm{Э}_\alpha(-\beta,t-\xi)\ d\xi, \quad \beta>0,\ o<\alpha<1, \qquad (6)$$

where $\mathrm{Э}_\alpha$ is Robotnov function, A, C, μ, β, α are the rheological parameters of the material, defined by the experiment. Summarizing the obtained results we can make the following conclusion, for the description of the rheologioal properties of the natural ageing polymers and composites on their base the hereditary ageing theory can be used.

<u>The fracture pecularities of ageing viscoelastic materials with the cracks.</u> The critical meaning of stress intensity factor K_c^* for the experimental materials was defined on the samples 296x40x0,18 mm with the central crack. Three group of samples with the cracks 5mm, 10mm and 15mm long were investigated. For each age of material 6 samples were taken. The critical meaning of stress intensity factor was defined by the formula

$$K_c^*=\sigma\sqrt{\pi l\ \sec(\pi l/2b)}, \qquad (7)$$

where σ is the fracture stress, l is the semi-length of the crack, 2b is the width of the sample. The analysis of the obtained data showed that the critical meaning of the stress intensity increases with the material age and in 20 years, it'll equal approximately 25%. Such increase as we'll show it further, leads to the subtantial decrease of the crack growth speed. The specific surface energy γ was defined by the experimentally found K_c^* and E from the equation

$$\gamma=K_c^{*2}/2E. \qquad (8)$$

In 20 yers γ increased by 25%.
The defined meanings of K_c^*, σ_b and E allow to estimate the influence of material ageing on the value of the pre-fracture area in the crack tip. For Leonov-Panasyuk-Dugdle-Barenblatt crack model the length of the pre-fracture area is

$$d=\pi K_c^*/8\sigma_0^2\ , \qquad (9)$$

where σ_0 is the limit of brittle rigidity. In this paper we consider that $\sigma_0=\sigma_b$. The analysis of the obtained result shows that the value of pre-fracture area decreased with the age and in 20 years it decreased by 6,5%. Taking into account the difficulties in defining experimentally the crack-tip opening displacement the analysis of this characteristic was done. We found that δ_c decreases negligibly with the age and has the incidental character, as δ_c is defined from the indirect experiments by the meanings of three characteristics (K_c^*, E, σ_b). Therefore we may consider that for the given material δ_c doesn't change practically with the age. The locus of the subcritical crack growth is built on the base of the experiment with the central cracks, 10 mm long in the samples 298x40x 0,18 mm. In Fig.2 it is shown the locus of the subcritical crack growth of the triacetate film of different ages when the external load p=23,6 MPa and the initial stress intensity factor K_{IC}=3,2 MPa * $m^{1/2}$.

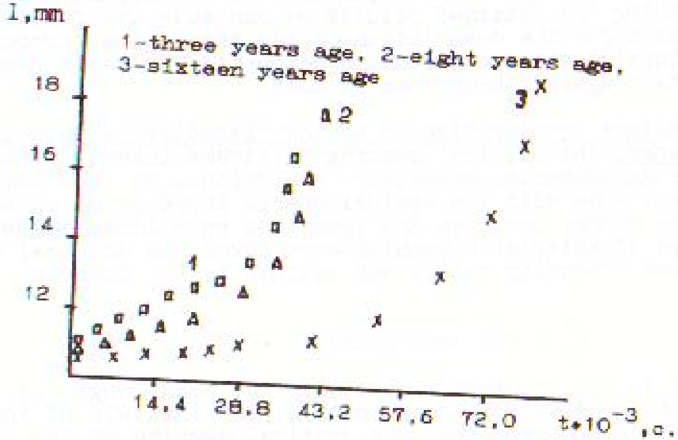


Fig.2

The analysis of the experimental data shows that the incubation and charpy periods have considerably less time interval (1 sec.), than the main period. The crack speed with the age of the material decreases. The approximate speed of crack growth decreases by 10^5-10^8 times for 20 years of ageing. The decreasing of speed can be explained by the processes of ageing taking place in the material which lead to the increasing of σ_b and K_c^*. In order to explain some assumptions we'll analyse the results on the base of the equation of crack growth in viscoelastic material obtained by Kostrov and Nikitin (1970) on the base of Leonov-Panayuk-Dugdale-Barenblatt crack model. We'll write this equation for the crack growth in viscoelastic ageing material of the same age

$$(K_{ci}^* / K_I)^2 = 1 + (d(t)/\, l(t)) \int_0^1 R(d(t)s \,/\, l(t)) F(s)\, ds \,, \quad (10)$$

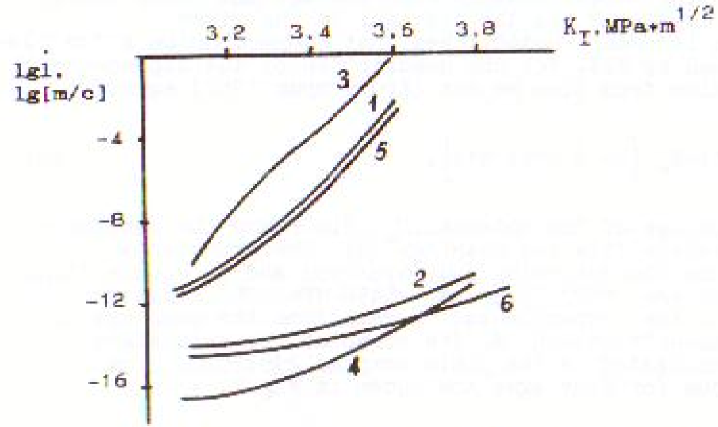
where $R(d(t)s / l(t))$ is the creep kernel, K_{ci}^* is the critical

meaning of the stress intensity factor for the given age of the material when $\dot{l}(t) \Rightarrow \infty$, d is the size of the pre-fracture area, index i is the meaning of the given value in the given age;

$F(s) = \sqrt{1-s} + (s/2)\ \ln((1-\sqrt{1-s})/(1+\sqrt{1-s}))$. Making the transformations in (10) we'll write the equation of the speed of the crack growth using Abel kernel

$$\dot{l}(t) = d_i \left[\frac{\lambda_i \sqrt{\pi}}{2(2-\alpha_i)\, \Gamma(2,5-\alpha_i)} \, \frac{1}{(K_{ci}^* / K_I)^2 - 1} \right]^{1/(1-\alpha_i)} , \quad (11)$$

where $d_i, \lambda_i, \alpha_i, K_{ci}^*$ are the parametrs, corresponding to the given material age. For defining the parameters which influence greatly on the speed of the crack growth in the process of ageing we write the parameters which depend on the material age and write the dependence of $\dot{l}(t) = f(K_I(t))$ (Fig.3). Among the parameters, which are changing in the process of viscoelastic material ageing and influencing greatly on the speed of crack growth we may choose the rheological parameters, K_c^* and their totality also. The sharp increase of crack speed and as a result the quick body fracture, takes place when the rheological material parameters where worsening.



1-three years age, 2-twenty three years age,
3-d≠const, K_c^*=const, rheological change.
4-K_c^*=$K_c^*(\tau)$, 5-d=d(τ).
6-d≠const, K_c^*=$K_c^*(\tau)$ and rheological change.

Fig.3

Crack Model. Fracture Criteria. The comparison of the theoretical and experimental results shows that they coincide qualitatively and in some cases quantitatively with the results for polymers and composites on their base, though the prognosis of the process of crack growth is based on the rather idealized model (Pestrikov ,1982). This gives the reason to use Leonov-Panasyuk-Dugdal-Barenblatt crack model in our further experiments. Let's examine the crack growth in the viscoelastic body with account of the peculiarities of material ageing using COD crack criterion (Knauss,1970; McCartney,1977,1979). Using the experimental data let's examine the most unfavourable case when the ageing influences greatly the rheological material parameters while the parameters of solidity and crack resistance change a little and they may be considered as constant (Pestrikov.1986).The equation of the macrocrack growth (d<<l) using the criterion COD for the given type of ageing viscoelastic material may be written in the following form by anology with Kostrov and Nikitin (1970) equation

$$\delta_c=\delta[l(t)] + \int_{t'}^{t} R(t,\tau)\ \delta[l(t),l(\tau)]\ d\tau, \qquad (12)$$

where t' is defined from the equation $l(t)-l(t')=d(t)$, $\delta[l(t)]=(8T_0\sigma/\pi)l(t)\ \ln\sec\alpha$, $\delta[l(t),l(\tau)]=(2T_0\sigma/\pi)\Phi[l(t),l(\tau)]$,

$\Phi[l(t),l(\tau)]$ is the function of geometrical & force parametrs, $\alpha(t)=\pi p(t)/2\sigma$, $p(t)$ is the value of external load, σ is the normal stress in the pre-facture zone.Having solved the equation (12) for the viscoelastic analogy of Griffith's task with account of linearization of $l(\tau)$ and $\alpha(\tau)$ function we have the following equation

$$l_*/l(t)=1+F(l,t,\tau,\alpha), \qquad (13)$$

where

$$F(l,t,\tau,\alpha)=\int_{t'}^{t}R(t,\tau)\Phi_1(\rho)d\tau+[2(\alpha/\dot{\alpha})+(1/\dot{l})]\int_{t'}^{t}R(t,\tau)\Phi_1(\rho)(\tau-t)d\tau+$$

$$+[(\dot{\alpha}/\alpha)^2+2(\dot{\alpha}/\alpha)(\dot{l}/l)]\int_{t'}^{t}R(t,\tau)\Phi_1(\rho)(\tau-t)^2d\tau+(\dot{\alpha}/\alpha)^2(\dot{l}/l)\int_{t'}^{t}R(t,\tau)$$

$$\Phi_1(\rho)(\tau-t)^3d\tau, \qquad (14)$$

$l_*=\pi\delta_c/8\sigma T_0(\alpha^2/2)$, l_* is the critical crack length.

For a number of construction materials the use of criterion COD leads to a great number of errors,because during the crack growth the condition $\delta(x,t)|_{x=l(t)}=\delta_c$ doesn't observe.The change

of the crack opening displacement in its growth may be considered as the deformation work in the crack tip. And proceeding from the energy conception we'll come to Knauss local energy criterion(1970). In comformity with the given type of viscoelastic ageing material,and the crack model this criterion may be written in the form

$$\int_{l(t)}^{L(t)} \sigma\,\frac{\partial}{\partial t}\{T_*[\frac{\sigma}{\pi}\,\phi(x_1,l(t))]\}\ dx_1=2\Gamma_0\dot{l}(t), \qquad (15)$$

where T_* is the integral operator with the non-diference creep kernel of the form (3),$L(t)=l(t)+d(t)$,$\phi(X_1,l(t))$ is the function of geometrical and force parameters.

For the case when the circumferential zone increases steadily the integration operation in the region $[0,d(t)]$ and the actions of the clock operator T_* are communicative we get the equation of crack growth from the criterion (15) and we will have the form

$$l_*/l(t)=1+(4/3)(d(t)/\dot{l}(t))(\dot{\alpha}(t)/\alpha(t))+F(l,t,\tau,\alpha), \qquad (16)$$

where $F(l,t,\tau,\alpha)$ is the form (14).

The Analysis of Equations of the Crack Growth by two criteria. The equation of microcrack growth resulting from Knauss criterion(1970) differs from the equation resulting from COD criterion only by the value $\Delta=4\ d(t)\dot{\alpha}(t)/[3\ \dot{l}(t)\alpha(t)]$. It is worth noting that this difference takes place only when we have the variable loads. Under the constant loads the equations coincide fully.The diagrams of crack growth resulting from Knauss criterion show that the cracks grow faster in this case and the life body is less than in case with COD criterion. This may be exlained by the fact that the equation resulting from Knauss criterion takes into account the behavior character of the loads in the process of crack growth. In the equation resulting from COD criterion it is very difficult to take into account these characteristics because there is the limitation on the critical meaning of crack opening displacement during its growth δ_c=const.

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