

BASIC KINETIC MODELS DEFORMATION-DESTRUCTION OF WOOD AND WOOD-BASED COMPOSITES

Existing models of kinetics of deformation-destruction (DD) are related mainly to the description of the transition from the undamaged state of the material into destroyed on one stage. The purpose of this study was to create the basic models of kinetics of deformation-destruction, which describe this process in the form of several successive transitions of separate structural elements (SE), in a material that deforms from one rheological state to another in time. It is established that the process of deformation-destruction can be considered as a process of gradual transition of the SE first of an elastic state, into viscoelastic and then destroyed. The change in the concentration of one or another SE can be determined experimentally by measuring the quantities that correlate with the parameters of deformation-destruction.

Keywords: models of kinetics, kinetics of deformation, criteria of destruction, two-stage model of deformation-destruction

ОСНОВНЫЕ КИНЕТИЧЕСКИЕ МОДЕЛИ ДЕФОРМАЦИИ-РАЗРУШЕНИЯ ДРЕВЕСИНЫ И КОМПОЗИТОВ НА ЕЕ ОСНОВЕ

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Существующие модели кинетики деформации-разрушения (ДР) связаны в основном с описанием перехода из неповрежденного состояния материала в разрушенное на одной стадии. Целью настоящего исследования являлось создание базовых моделей кинетики деформации-разрушения, описывающих этот процесс в виде нескольких последовательных переходов отдельных структурных элементов (СЭ), в материале, деформирующемся из одного реологического состояния в другое во времени. Установлено, что процесс деформации-разрушения можно рассматривать как процесс постепенного перехода СЭ сначала из упругого состояния, в вязкоупругое, а затем в состояние разрушения. Изменение концентрации того или иного СЭ может быть определено экспериментально путем измерения величин, коррелирующих с параметрами деформации-разрушения.

Ключевые слова: модели кинетики, кинетика деформации, критерии разрушения, двухстадийная модель деформации-разрушения.

Introduction

We take as the main hypothesis of the deformation that: first, the body is deformed and destroyed individually in separate elements of the structure. Namely, only in those elements in which the local stress first reaches the limits of proportionality, and then the limits of strength. In this case, the individual element of the structure is first elastically deformed, and then passes in series in a viscoelastic or plastic state, and then collapses. Secondly, a single destroyed element of the structure is surrounded for some time by non-destructive elements of the structure that are in an elastic or viscoelastic state. In-third, the body will be considered destroyed if the number of destroyed elements of the structure exceeds certain predefined values.

Thus, the kinetics of the destruction of the body under the action of thermomechanical loading will consist of different variants of the sequence of transition of the elastic elements of the structure (E) into the viscoelastic elements of the structure (VE), and then in the destroyed elements of the structure (D): $E \rightarrow VE \rightarrow D$.

Mathematical model of deformation-destruction process. The main variables that characterize the state of the system, determine the substances A_i , that is in different rheological states. Denote the number SE in different states as N_i ; n – is the vector of quantities components. Denote the concentration: $C_i \equiv N_i / V$.

Each stage of the system is matched by its speed $W_s(C, T)$. The velocity of the stage is intense and is defined as a function of intense quantities – concentration and temperature.

The kinetics equations have the following in coordinate form:

$$\frac{dN_i}{dt} = V \sum_s \gamma_{si} W_s(C, T) \quad i = 1, \dots, n, \quad (1)$$

where γ_{si} – is the stoichiometric vector with components $\gamma_{si} = \alpha_{si} - \beta_{si}$;
 s – stage;

α_{si} , β_{si} – non-negative integers are stoichiometric coefficients. In the absence of autocatalysis, as in our case, this vector completely determines the stoichiometric equations of the stage.

For each material, there are a priori restrictions on vectors γ_{si} – linear conservation laws (balance ratios). If N_{si} – the number of structural elements that are in a certain rheological state and k is a species in the molar volume of a substance A_i , then for any s and k :

$$\sum_i \alpha_{si} N_{ki} = \sum_i \beta_{si} N_{ki} \quad \text{or} \quad \sum_i \gamma_{si} N_{ki} = 0. \quad (2)$$

The balance relations (2) give rise to linear conservation laws for system (1), that is, for any k : $\sum_i \alpha_{si} N_{ki} = \text{const}$, means:

$$\frac{d}{dt} \sum_i \alpha_{ki} N_i = V \sum_{s,i} \alpha_{si} \gamma_{ki} W_s = 0. \quad (3)$$

Then the following kinetic model of the DD process will correspond to the transformation scheme (3):

$$\frac{dCA(t)}{dt} = -k_1 CA(t). \quad (4)$$

$$\frac{dCB(t)}{dt} = k_1 CA(t) - k_2 CB(t). \quad (5)$$

$$\frac{dCC(t)}{dt} = k_2 CB(t), \quad (6)$$

with initial conditions, $t = 0$: $CA(0) = 1$; $CB(0) = CC(0) = 0$, and boundary conditions: $CA(t) + CB(t) + CC(t) = 1$, where $CA(t) \in (1 \dots 0)$ – the current concentration of structural elements that are in an undamaged, elastic state at time t ; $CB(t) \in (0 \dots 1)$ – the current concentration of structural elements that are in a non-destructive, ie viscoelastic state at time t ; $CC(t) \in (0 \dots 1)$ – the current concentration of the structural elements that are in a destroyed state at time t ; k_1 – the rate constant of the transition of structure elements from elastic state to viscoelastic, s^{-1} ; k_2 – the rate constant of the transition of the elements of the structure from the viscoelastic state to the destroyed, s^{-1} .

Materials and methods

Three commercially-produced structural particleboard bonded with urea formaldehyde resin (UF) were provided by Kronospan UA Ltd., for this study: melamine faced particleboard (MF PB) according to EN 14322; veneered by oak particleboard (VF PB) according to EN 316, EN 622-5 and particleboard P2 (P2 PB) according to EN 312 – type P2; EN 13501-1: class D-s1, d0. For each type, two regular-size (2750 × 1830 mm) of boards with thicknesses of 18 mm were cut into 450 mm (length) × 50 mm (width) pieces. Before cutting, panels were stored in a conditioning room maintained at 20 °C and 65 % RH.

Static 3-point bending tests were carried out in the special test machine with temperature-controlled chamber (BOIKO *et al.* 2013). Specimens were prepared and cut according to ASTM D 1037-99. Loading and deflection were measured, and MOR and MOE were calculated according to Section 9 in ASTM D 1037-99. Investigated temperatures were 20 °C and 60 °C.

Since the change in the SE concentrations in one state or another can be given as a first order kinetic dependence (REGEL *et al.* 1974, PETROV *et al.* 1993), we can to write: $\frac{dCA(t)}{dt} = -k_1 CA(t)$ or, having gone to proportional deformation:

$$\frac{d\varepsilon_e(t)}{dt} = -k_1 \varepsilon_e(t). \quad (7)$$

We integrate (12) after separation of variables (time, deformation):

$$\frac{d\varepsilon_e(t)}{\varepsilon_e(t)} = -k_1 dt, \quad \int_{\varepsilon_1}^{\varepsilon_2} \frac{d\varepsilon_e(t)}{\varepsilon_e(t)} = -\int_{t_1}^{t_2} k_1 dt, \quad \ln\left(\frac{\varepsilon_1}{\varepsilon_2}\right) = -k_1 (t_2 - t_1), \quad k_1 = -\frac{1}{(t_2 - t_1)} \ln\left(\frac{\varepsilon_1}{\varepsilon_2}\right). \quad (8)$$

As we can see, when the deformation changes ε_1 to ε_2 by the same number of times the value of k_1 does not change. This allows for the creation of a kinetic model of deformation-destruction to replace concentrations proportional to their values – deformations, stresses, acoustic or electromagnetic emission pulses, quantities of matter, etc.

Results and discussion

Experimental studies of the long-term strength curve of PB, have found that the material behaves in a complex viscoelastic manner during the creep. And the curve of its deformation contains the recurring sections, characteristic for the curves of elastic and viscoelastic deformation (Fig. 1).

According to the graph of the basic deformation diagram (basic long-term strength curve) Fig. 1 we define such quantities: $t_1 = 0.003 \cdot 3600 = 10.8 [s]$, $\varepsilon_1 = 80 [\mu m]$, $t_2 = 200 \cdot 3600 = 7,2 \cdot 10^5 [s]$, $\varepsilon_2 = 730 [\mu m]$, $t_{cr} = 477 \cdot 3600 = 1,717 \cdot 10^6 [s]$. By Eqs. (8), we define: $k_1 = 0,307 \cdot 10^{-5} s^{-1}$, $k_2 = 0,719 \cdot 10^{-6} s^{-1}$, $\alpha = 4,273$.

In Fig. 2 shows a basic model diagram, constructed in the coordinates of the “concentrations of SE in different states – time”.

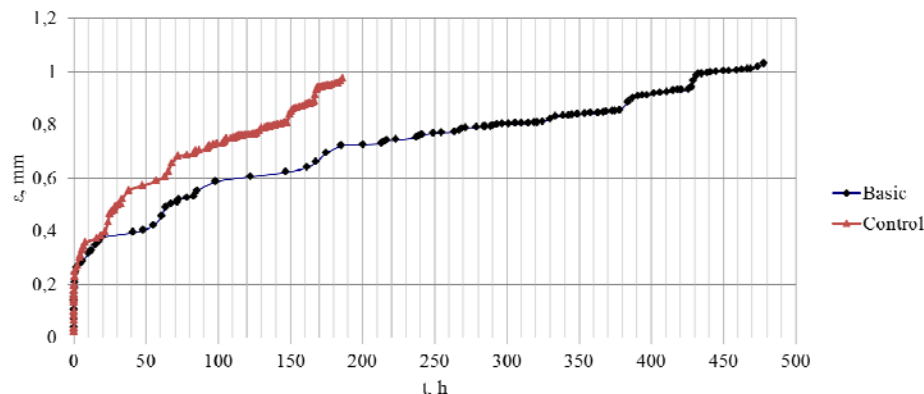


Fig. 1. Basic and control creep diagrams.

Dependences of the average absolute deformation for one group of the samples VF PB by stress level $SL = 15.4 \text{ MPa}$ and temperature $T = 20 \text{ }^\circ\text{C}$ for basic diagram, and by stress level $SL = 17.7 \text{ MPa}$ and temperature $T = 20 \text{ }^\circ\text{C}$ for control (predicted) diagram

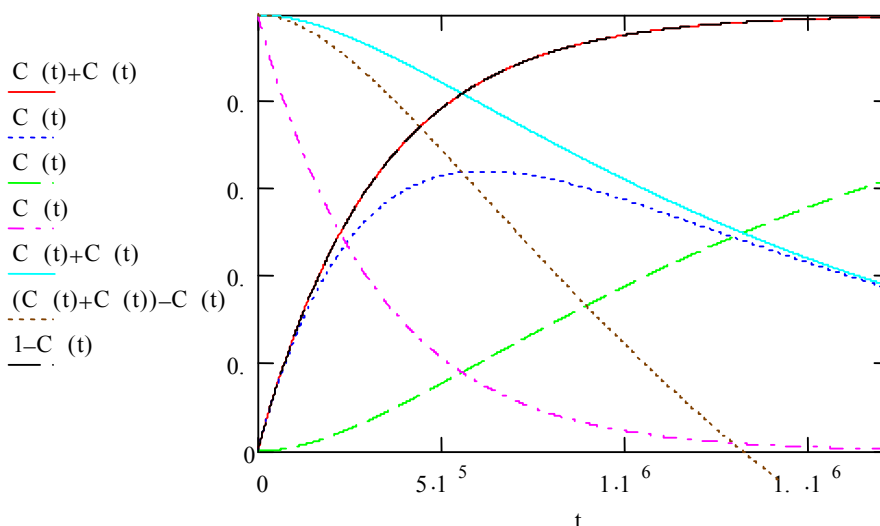


Fig. 2. Basic model diagram of long-term strength (creep): change concentrations of SE in the states: elastic - $CA(t)$, viscoelastic - $CB(t)$, destroyed - $CC(t)$ in time for the basic deformation diagram

Conclusions

1. For the first time, a two-stage nonlinear kinetic model of resource loss due to the creep of wood-based composites is proposed.
2. The use of formal kinetics methods for modeling the physicochemical processes that occur during deformation-destruction allows to design the multi-stage kinetic models.
3. The use of the method of basic deformation diagrams in combination with the two-stage description of the process of accumulation of damage, allows to increase the accuracy of the prediction of allowable time under different load schemes during creep.

References

1. Boiko L., Grabar I., Kulman S. 2013. Durability particleboards in furniture. *Osvita Ukrainy*, Ukraine, 2013, 210 p.
2. Petrov V. A., Bashkarev, V. I., Vettergen, V. I. 1993. Physical basis for predicting the durability of structural materials. St. Petersburg : Polytechnicak, 1993. 475 p.
3. Regel V. R., Slutsker A. I., & Tomashevsky E. E., 1974. Kinetic nature of the strength of solids : monograph. M., Science, 1974. 560 s.
4. Regel V. R. 1964. High-molecular compounds. No. 6, 1964. 395 p.