THE PUBLISHING HOUSE
OF THE ROMANIAN ACADEMY

PROCEEDINGS OF THE ROMANIAN ACADEMY, Series A,
Volume 14, Number 2/2013, pp. 152–160

THE PRINCIPLE OF CRITICAL ENERGY, CONSEQUENCES AND APPLICATIONS

Valeriu V. JINESCU

"Politehnica" University of Bucharest
Splaiul Independenței, no.313, Bucharest, Romania
E-mail: vvjinescu@yahoo.com

The principle of critical energy (PCE) and the concept of specific energy participation introduced by this principle, a dimensionless power dependent variable, allows the superposition of effects via algebraic summation, in the case of loads of the same nature but of different types, as well as in the case of loads of different nature (mechanical, thermal, electrical, magnetic, chemical etc.). There are three consequences of the principle: the law of the equivalence of processes and phenomena; the law of the coexistence and complementarity of order and disorder; the method of Energonics for strength and rigidity calculation. There are presented the numerous applications of this principle: the superposition of effects in materials with nonlinear behaviour in the calculation of rigidity (structure buckling, mechanical vibrations), of strength in crack free structures and cracked structures, in electromechanical loads, electromagnetic loads, in overconductivity etc.

Key words: principle of critical energy, law of the equivalence of processes and phenomena, fatigue, buckling, multiaxial loading, electromechanical loads, overconductivity.

1. INTRODUCTION

Science has become, in some of its chapter, a conglomerate of experimental data, details and theories out of which it is necessary to extract the fundamentals. One feels increasingly more the need for generalization, of stating some principles and universal laws, all of them likely to be applied to the greatest number of chapters in to which the contemporary science is divided.

The principle of critical energy (PCE) that I put forth and stated in 1984 [1–4] is a candidate to being such a general principle. It is the principle that allows the superposition or accumulation of the effects of various actions upon a material body, by considering its behavior. With the linear behavior of a material, under n loads of the same nature, the total effect, X, in general, is equal to the algebraic sum of partial effects, X_i and $X = \sum_{i=1}^{n} X_i$, respectively. If the material behavior is nonlinear, the total effect is different from the sum of partial effects [5], $X \neq \sum_{i=1}^{n} X_i$.

If loads of different nature (mechanical, thermal, chemical, electric, magnetic etc…) are at work upon a material with nonlinear behavior, how can effect cummulation occur? Will the same loads applied successively or simultaneously yield the same effect? How can one take into consideration, in our calculations, the deterioration produced by preloading, creep, vibrations etc.? All these questions get their answer by using PEC.

2. MATTER BEHAVIOUR, SPECIFIC ENERGY AND THE PRINCIPLE OF CRITICAL ENERGY (PCE)

One considers a material body under the loadings Y_i, where $i = 1, 2 \ldots k$. The loads Y_i may be of the same nature but of different types (for example mechanical: force, bending moment, torsion moment, pressure or of different nature (mechanical, thermal, chemical, electric, magnetic, biophysical etc. As a result, one obtains effects X_j, where $j = 1, 2 \ldots m$. Each loading carries a certain amount of active or action energy, $E_i(Y_i)$, while each effect corresponds to a certain amount of resulting energy, $E_j(X_j)$.

The correlation between action Y_i and the corresponding effect X_i represents the *law of matter behavior* with respect to the nature /type of load. In the general case of nonlinear power law behavior

$$Y_i = C_i \cdot X_i^{k_i}, \tag{1}$$

where C_i and k_i are material constant. If $k_i = 1$ one obtains a linear law behavior, used in many chapters of science (Hooke's law in deformable solid mechanics, Ohm's law in electrodynamics, Newton's law in viscous fluid mechanics, Fourier's law in thermodynamics etc…).

Energy represents the capacity of a physical system of doing work, when passing from a state into another state. This allows its correlation with matter behavior (1). The specific energy (J/m^3 or J/kg),

$$E_s = \int_0^X Y \cdot \mathrm{d}X. \tag{2}$$

The relations (1) and (2) give,

$$E_s = C \cdot X^{k+1} / (k+1) = Y^{\left(\frac{1}{k}+1\right)} \Big/ \left[(k+1) \cdot C^{1/k}\right]. \tag{3}$$

After analyzing the phenomena and the processes, one has found that throughout their evolution there exists the possibility of at least one jump or quantitative and/or qualitative discontinuity (bars, plates and shells buckling, resonance of mechanical or electromagnetic structures, some thermal phenomena etc.). The correspondent of each discontinuity is a certain value of specific energy called critical specific energy, $E_{s,cr}$ (as follows from the *law of the critical state of matter*) [4]. Discontinuity is marked by attaining the critical values X_{cr} and Y_{cr}. Consequently, the critical specific energy is written,

$$E_{s,cr} = C \cdot X_{cr}^{k+1} / (k+1) = Y_{cr}^{\frac{1}{k}+1} \Big/ \left[(k+1) \cdot C^{1/k}\right]. \tag{4}$$

Starting from the concept of energy, a unifying concept, common to all the chapters of science, it has been created Energonics [2]. One of the *principles of Energonics* is the *principle of critical energy* (PCE). Energonics is the "common" ground of all the chapters of science resorting to the use of the concept of energy.

Starting from the analysis of a great number of different phenomena and processes, the principle of critical energy was stated [1 – 4]: "*The critical state in a process or phenomenon is reached when the sum of the specific energy amounts involved, considering the sense of their action, becomes equal to the value of the specific critical energy characterizing that particular process or phenomenon*". The mathematical expression of the principle is,

$$\sum_i \left(E_s / E_{s,cr}\right)_i \cdot \delta_i = 1, \tag{5}$$

where δ_i = 1; 0 or – 1, if the action of energy $E_{s,i}$ is *in the sense*, *has no effect upon* or *opposes the process or phenomenon*.

The expression from the left member of relation (5) was named *the participation of the specific energy* $E_{s,i}$ and was written as [1; 5]

$$P_i = \left(E_s / E_{s,cr}\right)_i \cdot \delta_i. \tag{6}$$

The *total participation of the specific energies*, is the sum of the individual participations, P_i,

$$P_T = \sum_i P_i. \tag{7}$$

For real materials, for deteriorated materials, instead of the relationship (5) one writes

$$P_T = P_{cr}(t), \tag{8}$$

where $P_{cr}(t)$ is the *critical participation*, a dimensionless parameter time dependent, which ranges over an interval, $P_{cr}(t) \in \lfloor P_{cr,\min}; P_{cr,\max} \rfloor$, due to stochastic values of the matter characteristics. $P_{cr,\max} \le 1$ corresponds to the maximum probability of attaining the critical state. Generally, if:

$P_T < P_{cr}(t)$ – subcritical state; $P_T = P_{cr}(t)$ – critical state is reached; $P_T > P_{cr}(t)$ – supercritical state.

The influence of the irreversible effects (like thermal effects, deterioration, prestressing etc.) are included in the value of $P_{cr}(t)$. One notes with $D(t)$ the deterioration of matter as a nondimensional parameter with values between zero and unit. $D(t) = 0$ – for unstressed matter (at $t = 0$) and $D(t) = 1$ – for matter totally degraded [6]. The critical participation depends on time, *t*, through $D(t)$, as follows [5],

$$P_{cr}(t) = P_{cr}(0) - D_T(t), \tag{9}$$

where $P_{cr}(0)$ is the value of P_{cr} at $t = 0$. If the matter characteristics correspond to 100% probability of failure then $P_{cr}(0) = 1$, but if the matter characteristics correspondent to a minimum probability of fracture, than $P_{cr}(0) = P_{cr,\min}$. Generally we accept,

$$P_{cr}(t) = 1 - D_T(t). \tag{9}$$

The total deterioration $D_T(t) = \sum_i D_i(t)$ is a sum of *the partial deteriorations* $D_i(t)$.

In the case of non-linear behavior of the material (1) out of relation (3) – (8), one obtains,

$$\sum_i (Y/Y_{cr})_i^{\alpha+1} \cdot \delta_i = P_{cr}(t), \tag{10}$$

which is the PCE expression *with respect to the critical state*, where $\alpha = 1/k$ and *k* becomes from the law $\sigma = M_\sigma \cdot \varepsilon^k$ (σ – natural normal stress; ε – natural strain; M_σ, *k* – material constants). The exponent $\alpha = 1/k$ depend on the rate of loading: $\alpha = 1/k$ – when the load is applied static; $\alpha = 1/2k$ – if the load is applied rapidly; $\alpha = 0$ – in the case of shock loading [4; 7]. This principle allows the solution to the problem of superposition of effects when loading materials with nonlinear behavior, irrespective of the nature of external action, Y_i; it contains a sum of dimensionless parameter.

If α has the same value, then the simultaneous or successive loading under Y_i gives the same result as P_T. If, however, α has various values, as a result of applying loads with various rates, the value of P_T when the loads are simultaneously applied, may be different from applying them successively. In this case, the order of applying the loads has an influence upon the result, the value of P_T [2].

If $E_{s,cr}$ is replaced with the allowable specific energy $E_{s,al}$, then the *participation of specific energy with respect to the allowable state* is obtained. The loading state is allowable if

$$\sum_i (Y/Y_{al})_i^{\alpha+1} \cdot \delta_i \le P_{al},$$

where $Y_{al,i} = Y_{cr,i}/c_{Y_i}$ is the allowable value of Y_i and c_{Y_i} is safety coefficient. The allowable participation in the case of $P_{cr}(0) = 1$ is $P_{al} = 1 - D^*(t)$, where $D^*(t)$ is the matter deterioration calculated with respect to allowable state.

3. CONSEQUENCES OF THE PRINCIPLE OF CRITICAL ENERGY

Using the concept of specific energy participation (6) introduced by the PCE, two new laws have been stated [3, 4, 8, 9] and a method for strength calculation, named *Energonics method* [10].

• The law of coexistence and complementary of order and disorder [3, 8]: "*In any process or phenomenon, the sum of the participation in creating order and the participation in creating disorder is equal to the unit*".

The order and disorder motions coexist and are complementary, such as $P_{ord} + P_{des} = 1$, where P_{ord}, P_{des} is the participation to order and disorder, respectively (subunitary variables).

• The law of the equivalence of processes and phenomena [3, 9]: "*Any two phenomena, at a given time, are equivalent if the total participation of their involved specific energy, compared to the same critical state, are equal*". Generally one should write $P_{T,1}(t) = P_{T,2}(t)$, where $P_{T,1}(t)$, $P_{T,2}(t)$ is total specific energy participation dependent on time, *t*, for process 1 and for process 2. Both or only one of this participations may be time independent.

• *Energonics method,* in order to determine the equivalent stress in nonisotropic structures with nonlinear behavior, was developed on the basis of PCE and the law of equivalence of processes and phenomena [10].

One considers a nonisotrope body, where the main normal directions are x_1, x_2 and x_3. On the three main sliding planes the critical shear stresses are $\tau_{1,cr} = k_{11} \cdot \sigma_{1,cr}$; $\tau_{2,cr} = k_{21} \cdot \sigma_{1,cr}$; $\tau_{3,cr} = k_{31} \cdot \sigma_{1,cr}$, where $\sigma_{1,cr}$ is the critical normal stress on the direction of the main stress x_1, while k_{11}; k_{21} and k_{31} – numerical factors. One considers the loading under the main normal stresses σ_1, σ_2 and σ_3. With the method of Energonics there has been obtained the uniaxial stress (on direction x_1) equivalent to the triaxial loading [5],

$$\sigma_{1,ech} = \left\{ \frac{\left[(\sigma_1 - \sigma_2)/k_{31}\right]^{\alpha_1+1} + \left[(\sigma_2 - \sigma_3)/k_{11}\right]^{\alpha_1+1} + \left[(\sigma_3 - \sigma_1)/k_{21}\right]^{\alpha_1+1}}{\left(1/k_{21}\right)^{\alpha_1+1} + \left(1/k_{31}\right)^{\alpha_1+1}} \right\}^{\frac{1}{\alpha_1+1}}, \tag{11}$$

where $\alpha_1 = 1/k_1$, becomes from the power law $\tau = M_\tau \cdot \gamma^{k_1}$ (τ – natural shear stress; γ – natural shear strain; M_τ, k_1 – material constants). For an isotropic material $(k_{11} = k_{21} = k_{31})$, out of relation (11),

$$\sigma_{1,ech} = \left\{0.5 \cdot \left[(\sigma_1 - \sigma_2)^{\alpha_1+1} + (\sigma_2 - \sigma_3)^{\alpha_1+1} + (\sigma_3 - \sigma_1)^{\alpha_1+1}\right]\right\}^{\frac{1}{\alpha_1+1}}. \tag{12}$$

For materials with linear-elastic behavior ($k_1 = 1$ and $\alpha_1 = 1$) relation (12) changes into the relation of the equivalent stress corresponding to the theory of distortion energy (Huber, Hencky, von Mises).

4. APPLICATIONS OF THE PRINCIPLE OF CRITICAL ENERGY

There have been solved some cases of superposition of effects in engineering science and in fundamental sciences. In *engineering sciences*: in calculation the rigidity structures (structure vibration [2–4], structures buckling [2, 12]); in strength calculations (fatigue loading [13–16], multiaxial isothermal loading [17;18], fracture mechanics [19;20], loading under creep conditions [15, 21], electromechanical and thermoelectromagnetic loading [22], mechanical loading under corrosion [5, 23]).

In *some chapters of fundamental science*: the superposition of effects in determining glass transition temperature [24, 25]; in the phase transformations of substances [25], Dalton's and Amagat's law and a generalization of these laws [2, 26], as well as superposition of the effects of various actions upon live bodies [4].

The PCE has allowed finding the fatigue life of technical structures with cracks [27] and was analysed from the thermodynamic point of view and was underlined its high degree of generality [28].

a. The total participation in releasing the buckling in any kind of shells, under external pressure p_e, axial force *F*, bending moment M_b, torsion moment M_t, shearing force *Q* and magnetic induction *B* [4, 12],

$$P_T = \left(p_e/p_{e,cr}\right)^{\alpha+1} + \left(\sigma_1/\sigma_{1,cr}\right)^{\alpha+1} \cdot \delta_F + \left(\sigma_b/\sigma_{b,cr}\right)^{\alpha+1} \cdot \delta_b + \left(\tau_t/\tau_{t,cr}\right)^{\alpha_1+1} + \left(\tau/\tau_{cr}\right)^{\alpha_1+1} \cdot \delta_Q + \left(B/B_{cr}\right)^{\beta} \cdot \delta_B,, \tag{13}$$

where $\sigma_1 = F/A$; $\sigma_b = \pm M_b/W$; $\tau_t = M_t/(A \cdot R)$; $\tau = Q/A$; $A = 2\pi R \cdot \delta$; W – strength module of shell section, R – the radius and δ – the thickness of the shell wall. The denominators represent the critical values corresponding to the buckling only under the action of that particular load, while δ_F, δ_b, δ_Q and δ_B are equal to 1 on the surfaces where those loads produce compression and to -1 on the surfaces where those loads produce extension. Exponent β derives from the behavior law of the shell material under the action of magnetic induction. In the case of normal stresses and of loads inducing such stresses, in law (1) one uses exponent $\alpha = 1/k$, while in the case of shear stresses the exponent α is replaced with $\alpha_1 = 1/k_1$.

For linear elastic behavior $(\alpha = \alpha_1 = 1)$, by loading only under external pressure p_e and meridional compression stress σ_1, the critical state is obtained out of relation (8) and (13):

$$\left(p_e/p_{e,cr}\right)^2 + \left(\sigma_1/\sigma_{1,cr}\right)^2 = P_{cr}(t). \tag{14}$$

This is the equation of a circle with radius $\sqrt{P_{cr}}$. Figure 1, a presents, for cylindrical shells, the experimental points for different values of ratios L/R and R/δ [29], where R, L and δ are the radius, length and thickness of the shell wall. The experimental points feature stochastic distribution, most of them being included between the circles drawn with relation (16) for $\sqrt{P_{cr,\min}} = 0.85$ and $\sqrt{P_{cr,\max}} = 1.0$.

With the relation (14) there have been justified theoretically 31 empirical relations deduced for cylindrical shells, curved plates, plane plates and bars [4;12];

b. Shaft fundamental bending vibration under an axial loading [2],

$$\omega_{cr}(F) = \omega_{cr} \cdot \left[1 - \left(F/F_{cr}\right)^{\alpha+1} \cdot \delta_F\right]^{0.5}, \tag{15}$$

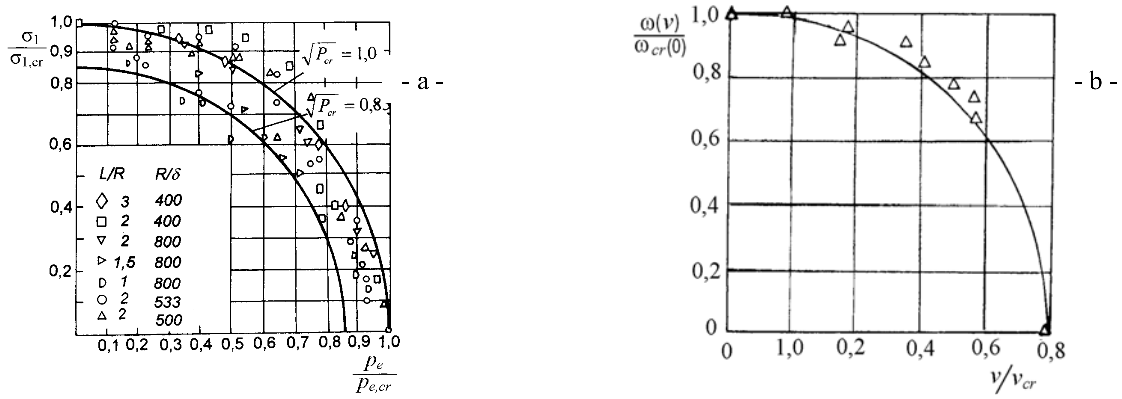

Fig. 1 – Dependence of $\sigma_1/\sigma_{1,cr}$ and $p_e/p_{e,cr}$ deduced experimentally (points), for cylindrical shells with different ratios L/R and R/δ [29] and the curves drawn with relation (14) for $\sqrt{P_{cr}} = 0.85$ and 1.0 (a); dependence of $\omega(v)/\omega_{cr}(0)$ and v/v_{cr} drawn with relation (20) and the points deduced experimentally (reported in [30]).

where ω_{cr} is the shaft fundamental bending vibration; F_{cr} – buckling force of the shaft; $\alpha = 1/k$ and $\delta_F = 1$ for a compressive force F, while $\delta_F = -1$ if F is an elongational force. For a linear – elastic material $(\alpha = 1)$ relation (15) becomes a well known one reported in [31];

c. The own pulsation of a tube through which flows a Newtonian fluid with the mean speed v, results from the superposition of effects and is written as [4],

$$\left(\omega/\omega_{cr,0}\right)^2 + \left(v/v_{cr}\right)^2 = 1, \tag{16}$$

where $\omega_{cr,0}$ is the own pulsation of the fluidless tube; $\omega_{cr}(v)$ – the own pulsation of the tube fluid inflow with speed v, while v_{cr} – critical fluid speed (Fig. 1, b).

d. In the case of stress corrosion (superposition of stress loading and corrosion) under monotonic loading according to the PCE the failure takes place if the following condition is fullfield [4;23],

$$\left(\sigma/\sigma_u\right)^{\alpha+1}+\left(\tau/\tau_{cr}\right)^{\alpha_1+1}+\left(t/t_{cs}\right)^{c}=1\,, \tag{17}$$

where σ, τ are the applied normal and shear stress; σ_u, τ_u – ultimate normal, respective shear stress; t – time of general corrosion; t_{cs} – time until complete corrosion through the whole structure wall thickness undergoing corrosion; c – material constant [32].

e. Under fatigue loading of a sample with the normal stress amplitude σ_a and shear stress amplitude τ_a and under the normal mean stress σ_m and shear mean stress τ_m (Fig. 2), for total participation with respect to critical state [2, 13; 14],

$$P_T=\left(\sigma_a/\sigma_{-1}\right)^{\alpha+1}+\left(\sigma_m/\sigma_{m,cr}\right)^{\alpha+1}\cdot\delta_{\sigma_m}+\left(\tau_a/\tau_{-1}\right)^{\alpha_1+1}+\left(\tau_m/\tau_{m,cr}\right)^{\alpha_1+1}\delta_{\tau_m}\,,, \tag{18}$$

where $\sigma_{m,cr}$ and $\tau_{m,cr}$ are the critical mean stresses; σ_{-1}, τ_{-1} – fatigue limits.

From relations (8) and (18), in the case of linear - elastic material behavior $\left(k=k_1=1\right)$, with $P_{cr}\left(t\right)=1$, one obtains all the relations recommended and used in literature at high cycle loading. Under symmetrically alternating loading $\left(\sigma_m=\tau_m=0\right)$ results Gough şi Pollard relation [33],

$$\left(\sigma_a/\sigma_{-1}\right)^2+\left(\tau_a/\tau_{-1}\right)^2=1\,. \tag{19}$$

Under normal stress only $\left(\tau_a=\tau_m=0\right)$, for $\sigma_{m,cr}=\sigma_y$ (yield stress) one obtains Buzdugan's [34] relation (20) and Soderberg [12] relations (21). With $\sigma_{m,cr}=\sigma_u$ (ultimate stress) one obtains Goodman and Gerber relations (22) and (23) (Table 1). The values of exponents from relation (18) depends on the loading rate [2;7]. Consequently from (8) and (18) results the empirical relations established by Soderberg, Goodman, Gerber, Serensen and Morrow (21–25, Table 1).

Table 1

Relations for fatigue calculation

Buzdugan	*Soderberg*	*Goodman*	*Gerber*	*Morrow*	*Serensen*
$\left(\frac{\sigma_a}{\sigma_{-1,s}}\right)^2+\left(\frac{\sigma_m}{\sigma_y}\right)^2=1$ (20)	$\frac{\sigma_a}{\sigma_{-1,s}}+\frac{\sigma_m}{\sigma_y}=1$ (21)	$\frac{\sigma_a}{\sigma_{-1,s}}+\frac{\sigma_m}{\sigma_u}=1$ (22)	$\frac{\sigma_a}{\sigma_{-1,s}}+\left(\frac{\sigma_m}{\sigma_u}\right)^2=1$ (23)	$\frac{\sigma_a}{\sigma_{-1,s}}+\frac{\sigma_m}{\sigma_f}=1$ (24)	$\frac{\sigma_a}{\sigma_{-1,s}}+\frac{\sigma_m}{\sigma_{cr,0}}=1$ (25)
$\alpha=1$; $\sigma_{m,cr}=\sigma_y$.	$\alpha=0$ (shock); $\sigma_{m,cr}=\sigma_y$.	$\alpha=0$ (shock); $\sigma_{m,cr}=\sigma_u$.	$\alpha=0$ (shock) for σ_a and $\alpha=1$ (statical) for σ_m.	$\alpha=0$ (shock).	$\alpha=0$ (shock); $\sigma_{cr,0}=\frac{\sigma_{-1,s}\cdot\sigma_{0,s}}{2\sigma_{-1,s}-\sigma_{0,s}}$
σ_y – yield stress; σ_u – ultimate stress; σ_f – fatigue stress coefficient; $\sigma_{0,s}$ – structure fatigue limit for pulsating cycles.					

In the case of fatigue loading with several blocks of normal stresses $\left(\sigma_{a,i};\sigma_{m,i}\right)$, starting from relationship (18), the following law for fatigue life has been deduced [35],

$$\sum_i\left(n/N\right)_i^{(\alpha+1)/m}=1-\left(\sigma_m/\sigma_u\right)_f^{(\alpha+1)}\cdot\delta_{\sigma_m}-D_T\left(t\right), \tag{26}$$

where $\delta_{\sigma_m}=1$ if $\sigma_m>0$ and $\delta_{\sigma_m}=-1$ if $\sigma_m<0$; n_i, N_i is the number of effective loading cycles and fatigue life, respectively, for the its stress range; m – the exponent in Basquin's law $\left(\sigma_a^m\cdot N=\text{constant}\right)$; $\left(\sigma_m/\sigma_u\right)_f$ - the value of this ratio in the final (last) block of stresses; the deterioration $D_T\left(t\right)$ is analised in [36].

f. For *combined stresses*, of a bending stress σ_b and a torsion stress τ_t, the Energonics method leads to the following expression of the equivalent bending stress [4, 18]:

$$\sigma_{b,ech} = \left(\sigma_b^{\alpha+1} + K \cdot \tau_t^{\alpha_1+1}\right)^{\frac{1}{\alpha+1}}, \tag{27}$$

where $K = \left(\sigma_{b,cr}\right)^{\alpha+1} / \left(\tau_{t,cr}\right)^{\alpha_1+1}$. If σ_b is symmetrically alternating and τ_t is monotonic, then $K = \left(\sigma_{-1,s}\right)^{\alpha+1} / \left(\tau_u\right)^{\alpha_1+1}$. In the case of a linear – elastic behavior $\alpha = \alpha_1 = 1$, under monotonic loading, with $K = \sigma_y / \tau_y$ one obtains the relationship reported in [37].

g. In the fracture *mechanics* by superposition corresponding to the three failure modes (I; II; III), the following relation has been obtained corresponding to the critical state (fracture) [2],

$$\left(K_{\mathrm{I}}/K_{\mathrm{I}c}\right)^{\alpha+1} \cdot \delta_\sigma + \left(K_{\mathrm{II}}/K_{\mathrm{II}c}\right)^{\alpha_1+1} + \left(K_{\mathrm{III}}/K_{\mathrm{III}c}\right)^{\alpha_1+1} = P_{cr}(t), \tag{28}$$

where $K_{\mathrm{I}}, K_{\mathrm{II}}, K_{\mathrm{III}}$ are the mechanical stress intensity factors and $K_{\mathrm{I}c}$, $K_{\mathrm{II}c}$, $K_{\mathrm{III}c}$ – the corresponding toughness of the material. $\delta_\sigma = 1$ if $\sigma > 0$ (opens the crack) and $\delta_\sigma = -1$ if $\sigma < 0$ (clouses the crack).

In the particular case of linear-elastic behavior $(\alpha = \alpha_1 = 1)$ with $\sigma > 0$ and $P_{cr}(t) = 1$, the relation (28) becomes the following relationship obtained empirical [38],

$$\left(K_{\mathrm{I}}/K_{\mathrm{I}c}\right)^2 + \left(K_{\mathrm{II}}/K_{\mathrm{II}c}\right)^2 + \left(K_{\mathrm{III}}/K_{\mathrm{III}c}\right)^2 = 1. \tag{29}$$

For an aluminium alloy sample in the case of superposition of failure mode I and II, $P_{cr}(t) = 0.92\ldots1.0$ [39].

By mechanical and electrical loads superposition of piezoelectric ceramics, starting from the principle of critical energy the following relationship has been obtained,

$$\left(K_{\mathrm{I}}/K_{\mathrm{I}c}\right)^2 + \left(K_E/K_{Ec}\right)^2 = P_{cr}(t), \tag{30}$$

where K_E; K_{Ec} is the electrical intensity factor and the toughness under purely electrical loading, respectively defined by Zhang et al. [40]. Comparing with experimental data [40] one obtains $P_{cr}(t) = 0.9\ldots1.1$.

h. Under the mechanical stress loading σ of a conductor wherein flows an electric current with electric voltage *U*, the critical state, obtained through the superposition of effects is reached when [4; 22],

$$\left(\sigma/\sigma_{cr}\right)^{\alpha+1} + \left(U/U_{cr}\right)^{\alpha_u+1} \cdot \left(t/t_{cr}\right) = 1, \tag{31}$$

where *t* is the time of electrical voltage action *U*, while t_{cr} is the time beyond which the voltage action U_{cr} alone can destroy the conductor. Exponent $\alpha_u = 1/m$ derives from the nonlinear law of behavior $U = M_R \cdot I^m$, where M_R and *m* are material constants; *I* – intensity of electric current. In the case of linear behavior $m = 1$ and $\alpha_u = 1$. If *U* and U_{cr} correspond to the same duration, then $t = t_{cr}$.

i. The overconductivity of a resistor can be canceled either if it is applied only to a magnetic field whose intensity *H* is higher than critical intensity, H_{cr}, or if its temperature T (measured in K) is raised above a certain critical value T_{cr}. If, however, $H < H_{cr}$ and $T < T_{cr}$, the simultaneous action of the magnetic field and of heat can annihilate overconductivity if the sum of their participations $P(H) + P(T) = 1$ or [4],

$$\left(H/H_{cr}\right)^{\alpha+1} + \left(T/T_{cr}\right)^{\alpha_t+1} = 1, \tag{32}$$

where α and α_t come from the law of material behaviour of the conductor in the magnetic and thermal field respectively. With $\alpha = 0$ and $\alpha_t = 1$ one obtains the relation proposed in 1914, by Kamerlingh Onnes [41].

j. Dependence between the *magnetic hyperfine field ratio* $H_{hf}(T)/H_{hf}(0)$ and temperature ratio T/T_N, where $H_{hf}(T)$ is the hyperfine magnetic field at temperature *T* (in K); H_{hf} – the hyperfine magnetic filed at 0K; T_N –antiferromagnetic Néel temperature, on the basis of PCE,

$$\left(H_{hf}(T)/H_{hf}(0)\right)^{\alpha+1} + \left(T/T_N\right)^{\alpha_t+1} = 1. \tag{33}$$

With $\alpha = \alpha_t = 1$ this relation describes the dependence obtained experimentally for $FeBO_3$ [42].

5. CONCLUSIONS

The high degree generality of PCE comes from the introduction of the dimensionless concept of specific energy participation (which allows the summation of effects independent of the nature of loadings), from the introduction of the sense of external action and the correlation of participation of specific energy with the behaviour of the matter involved, which allows for the introduction of the loading rate. By correlating critical participation with material deterioration, the result obtained may be applied to engineering structures after they have undergone a certain process of deterioration (aging, fatigue, creep, corroding etc…). PCE is the principle that allows the superposition of effects both in the case of linear and nonlinear behavior for the structure under load. The principle of critical energy opens a window towards looking at reality and interpreting it in a totally different way. It may represent an important headways in unifying and simplification of the different "chapters" into which science is divided.

REFERENCES

1. JINESCU V.V., *Principiul energiei critice*, Revista de Chimie (Bucureşti), **35**, pp. 858, 1984.
2. JINESCU V.V., *Energonica,* Edit. Semne, Bucureşti, 1997.
3. JINESCU V.V., *Principiile şi legile energonicii,* Politehnica Press, Bucureşti, 2003.
4. JINESCU V.V., *Principiul energiei critice şi aplicaţiile sale,* Edit. Academiei Române, Bucureşti, 2005.
5. JINESCU V.V., *Tratat de termomecanică*, Vol. 1, Edit. AGIR, Bucureşti, 2011.
6. KACHANOV L.M., *Time of the rupture process under creep conditons*, Izv. Akad. Nauk SSSR, Techn. Nauk., pp. 26–31, 1968.
7. FAUPEL J.K., *Engineering Design*, Wiley Inc., New York, 1964.
8. JINESCU V.V., *Legea coexistenţei şi complementarităţii ordinii şi dezordinii*, Revista de Chimie, **52**, *3*, pp. 91–96, 2001.
9. JINESCU, V.V., *Legea echivalenţei proceselor şi fenomenelor şi aplicaţiile ei*, Revista de Chimie, **52**, *12*, pp. 768–773, 2001.
10. JINESCU V.V., *Calculul de rezistenţă pe baza energonicii în comparaţie cu calculele bazate pe teoriile actuale*, A IV-a Conferinţă a Academiei de Ştiinţe Tehnice din România, Iaşi, 19–20 noiembrie 2009, pp. 117–122.
11. RADEŞ M., *Rezistenţa materialelor*, Vol. 1, Edit. Printech, Bucureşti, 2004.
12. JINESCU V.V., *Stability determination of structures under a group of loads by using the principle of critical energy*, Int. J. Pres. Ves. & Piping, **48**, pp. 343, 1991.
13. JINESCU V.V., *Principiul energiei critice* II + III. *Aplicaţii în cazul solicitărilor variabile izoterme*, Revista de Chimie, **40**, *1*, pp. 67–72 and nr. 7, pp. 622–627, 1989
14. JINESCU V.V., *Principiul energiei critice* IV. *Aplicaţii în cazul solicitărilor variabile neizoterme*, Revista de Chimie, **40**, *8*, pp. 677–681, 1989.
15. JINESCU, V.V., *The Superposition of Effects Produced by Buckling, Creep and Fatigue*, Int. J. Pres. Ves. & Piping, **53**, pp. 377–391, 1993.
16. JINESCU V.V., *Fatigue Strength Calculation of Nonlinear Materials*, MOCM – 6, Romanian Academy, Iaşi, 2000, pp. 13–20.
17. JINESCU V.V., *Principiul energiei critice* V + VI. *Aplicaţii în cazul solicitărilor compuse*, Revista de Chimie, **41**, pp. 409–413 şi **41**, pp. 541–544, 1990.
18. JINESCU V.V., *The Energy Concept in Critical Groups of Load Calculation*, Int. J. Pres. Ves. & Piping, **38**, *3*, pp. 211–226, 1989.
19. JINESCU V.V., *Principiul energiei critice în domeniul mecanicii ruperii materialelor*, I + II, Revista de Chimie, **41**, pp. 209–216 şi **41**, pp. 305–308, 1990.
20. JINESCU V.V., *The Principle of Critical Energy in the Field of Materials Fracture Mechanics*, Int. J. Pres. Ves.&Piping, **53**, pp. 39–45, 1993.
21. JINESCU V.V., *Principiul energiei critice. Solicitări în condiţii de fluaj*, VII + VIII, Revista de Chimie, **41**, pp. 677–682; 769–771, 1990.
22. JINESCU V.V., *Suprapunerea efectelor solicitărilor electrice şi mecanice*, Revista de Chimie **48**, pp. 452–456, 1997.
23. JINESCU V.V., *Unele aplicaţii ale principiului energiei critice în chimie şi mecanochimie*, Revista de Chimie, **48**, pp. 5–8, 1997.
24. JINESCU V.V., *Principiul Energiei Critice.* I – *Grupări critice*, Revista de Chimie (Bucureşti), **33**, pp. 946 – 950, 1986.
25. JINESCU V.V., POPESCU, I., *Relaţie generalizată pentru calculul parametrilor stării critice ai unor substanţe*, Revista de Chimie (Bucureşti), **47**, pp. 105–112, 1996.
26. JINESCU V.V., *The High Degree Generality of the Principle of Critical Energy*, Revue Roumaine de Chimie, **34**, pp. 491–502, 1989.
27. JINESCU V.V., *The Lifetime of Mechanical Structures Subjected to Fatigue*, The Conference of *Excellence Research – A Way to Innovation*, Braşov, Vol. 2, Edit. Tehnică, pp. 222–1÷6, 2008.
28. PETRESCU S., *A critical state of matter criterion. Jinescu criterion*, Revista de Chimie (English ed.), **1**, *1/2*, pp. 13–19, 2000.
29. MATEESCU D., IVAN M., *Conducte circulare cu diametru mare*, Editura Tehnică, Bucureşti, 1985.

30. CIOCÂNEA, A., *Influenţa vibraţiilor asupra curgerii interioare unei ţevi*, PhD Thesis, "Politehnica" Univ. Bucharest, 1997.
31. PONOMARIOV, S.D., ş.a., *Calculul de rezistenţă în construcţia de maşini*, Vol. III, Edit. Tehnică, Bucureşti, 1963.
32. AMIRAL A., MOHAMED-CHATEAUNEUF A., CHAOUI K., *Reliability assessment of underground pipelines under combined effect of active corrosion and residual stress*, Int. J. Pres. Ves. & Piping, **83**, pp. 107–117, 2006.
33. GOUGH H.J., POLLARD H.V., *Properties of Some Materials for Cast Crankshafts with Special Reference to Combined Stress*, Proc. Inst. Automobile. Engrs., **31**, 1937, pp. 31.
34. BUZDUGAN GH., *O nouă metodă pentru calculul coeficientului de siguranţă la solicitările variabile prin cicluri asimetrice*, Studii şi Cercetări de Mecanică Aplicată, **4**, 1963, pp. 827.
35. V.V. JINESCU, *Critical energy approach for the fatigue life calculation under blocks with different normal stress amplitudes*, Int. J. Mechanical Sci., 2013; dx.doi.org/10.1016/j.ijmecsci. 2012.12.009
36. V.V. JINESCU, *Cumulation of effects in calculation the deterioration of fatigue loaded structures*, International Journal Damage Mechanics, **21**, pp. 671–695, 2012.
37. REŞETOV, D.N., *Organe de maşini,* Edit. Tehnică, Bucureşti, 1963.
38. CHANG J., XU J., MUTOH Y., *A general mixed-mode brittle fracture criterion for cracked materials*, Eng Fract Mech, **73,** 2006, pp. 1249–1263.
39. GDOUTOS, E.E., *Fracture Mechanics – an Introduction*, Second Edition, Springer, Dordrecht, The Netherlands, 2005.
40. ZHANG T.-Y., LIU G., WANG Y., TONG P., *Application of the concepts of fracture mechanics to the failure of conductive cracks in piezoelectric ceramics*, Eng. Fracture Mech., **74,** pp. 1160–1173, 2007.
41. POPESCU, I.M., *Fizica*, Vol. 2, Edit. Didactică şi Pedagogică, Bucureşti, 1983.
42. BURZO E., *Fizica fenomenelor magnetice*, Vol. 2, Edit. Academiei RSR, Bucureşti, 1979.

Rceived May 31, 2012