Chaotic Modeling and Simulation (CMSIM) 3: 327-341, 2018

"... Two dangers do not stop threaten the world: order and disorder ..."
Paul Valéry

NANOCHAOS in raising a machine reliability and the creation of "eternal" STRUCTURES

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Abstract. A synergetic model of construction destruction was built firstly from the point of modern physics and the theory of phase transitions "disorder - order" (at the atomic and nanostructured level). The principal different role of a chaos on the structural at various levels of construction under the temperature-load power - from positive to atomic level and nanoscale to negative at the meso level and sorely-negative on a macro level was shown. It was received a theoretical approach underlying parameter equation Zhurkov $\tau = \tau_0 \exp\frac{U_0 - \gamma\sigma}{kT}$- activation energy destruction Uo from this synergetic model of a destruction. Approximation of Professor Grabar $U_0 \cong kT_s \ln\frac{[1]}{\tau_0}$ for all bcc and fcc metals and their alloys gives the error not more than ± 1,6%, where τ - time to fracture; T - temperature test (operation activity); Ts - the melting point of the metal or alloy; $\tau_0 \sim 10^{-13}$ seconds - during the thermal vibrations of atoms; k - Boltzmann constant; γ - activation volume.

On the basis of this synergetic model was proposed a number of approximations to quantify the characteristics of durability and reliability of a wide class of metallic structural materials and formulation of innovative applications. This concept allows us to offer a strategy of "eternal" designs by periodic restoration of chaos in nanostructured level design of a construction. The ways of this "nano Chaos" were proposed.
Keywords: Chaos, Order, Nanostructures, "Eternal" structures, Physics of strength.

1. Introduction

From middle of 20 century in mechanics and physics of destruction in durable experimental works the phenomena, that was not laid in dominating ideology of physics of solid, mechanics of continuum, statistical physics- discreteness in behavior of enormous ensembles of oscillators, height rate of fatigue crack, discrete levels of descriptions of durability, appeared regularly, discrete levels of step of tireless furrows and others like that [1-2].

Received: 3 May 2017 / Accepted: 21 March 2018

ISSN 2241-0503

A synergetics uses three examples of self-organization of the nonequilibrium systems:

- it is generation of coherent radiation at the achievement of certain parameters of pumping (laser);
- it is formation of stationary convective streams that have a filoform (sels of Benar);
- concentration self-oscillations (reaction of Belousov-Zhabotinskiy).

Self-organization models partly made clear physical nature of the discrete phenomena in physics and mechanics of destruction. However on this time physical models that is able to decide next tasks are built:

- to show quantitative descriptions of data of the mako-discrete phenomena out of the first principles;
- to forecast descriptions of durability and reliability without subracing parameters;
- to explain huge dispersion of descriptions of durability and tiredness and its physical nature;
- to offer a theory anti-destruction, what would allow to take a construction from a critical condition and opened ways to creation of "eternal" constructions.

2. Statement of the problem

Processes that take place in construction material during exploitation - from the beginning of exploitation and to complete destruction - very difficult, because flow and show up simultaneously on many structural levels:

- A - an is the Atomic level (10^{-10} m) - separate atoms and monoatomic chains;
- N - nano level (10^{-9}…10^{-8} m) - nanostructures (nanoclusters of atoms);
- Mi - micro level (10^{-7}…10^{-5} m) - dislocations, disclinations and their ensembles;
- Me - meso level (10^{-5}…10^{-3} m) - a grainy structure;
- Ma - macro level (10^{-3}…10^{0} m) is a detail of construction (Fig. 1).

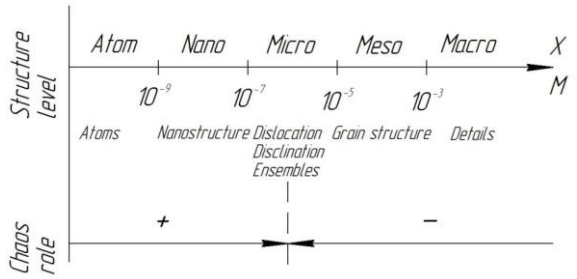

Fig. 1. The Structural levels in construction material on-loading and fundamentally different role of chaos

Thus first three levels are practically inaccessible for research and supervision in a dynamics, and not only from nano- and micro- sizes but also because it are dynamic ensembles with characteristic frequencies $\omega \sim 10^{10}\ldots10^{13}$ sec^{-1}. Therefore for their study it is necessary the methods of molecular dynamics in number to design kinetics of giant ensembles of nonlinear oscillators, as open system, that interchange energy, matter, information and entropy with an environment. Under the action of the operating temperature-power loading such stochastic nonlinear dynamic ensembles that are far from an equilibrium have a sense to formation of spatiotemporal structures with corresponding scale levels as a result of multilevel cascades of kinetic phase transitions as "disorder is an order" (Fig. 2).

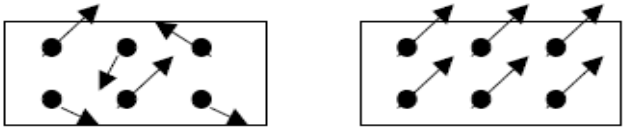

Fig. 2. Phase transition on a laser chart and formation of nanoclusters of order under the action of external external influence "temperature-time-loading"

It was shown, that on finite-dimensional objects phase transitions to such ensembles comes true not very rapidly, but as a step, as be considered, but as the kinetic process blurred out in time [12-15].

Thus in an infinitely measure ensemble are allocated (self-organizing) to nano ensembles ~30…70 interatomic distances, where a process of transition of micro ensemble is from the state with the low level of order - almost chaotic - (height of chaos $\lambda\rightarrow1$) - to practical complete efficiency (height of chaos $\lambda\rightarrow0$). Such efficiency in the dynamics of nano ensemble is fatal for the further fate of construction. In obedience to our sinergistical model of destruction, synchronization of nano ensemble allows to it to carry out a collective jump over the potential hurdle of U_o (Fig. 3).

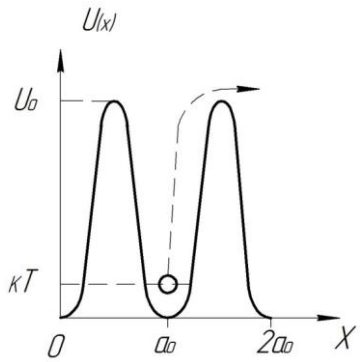

Fig. 3. Activated jump of group of oscillators over the potential hurdle

The Power and sentinel parameters of the activated jump of nanocluster (synchronized group of atoms) coincide with the parameters of the activated jump of separate atom!

And exactly this jump characterizes the offensive of irreversible event - beginning of development of crack (its localization). From this moment the fate of Shredinger cat (constructions) went across from an abeyance to the state of beginning of her catastrophic destruction.

3. Equation of Zhurkov and approaching of prof. Grabar.

This sinergistical model allows to explain many experimental facts of modern physics of destruction. In their time, developing approaches of Arrenius, Frankel, Eiring, Polyani, S. Zhurkov [3] offered kinetic equalization of process of destruction, as to the solid phase reaction. Kinetics of that reaction is determined by time, temperature and external power loading.

$$\tau = \tau_0 \exp \frac{U_0 - \gamma\sigma}{kT} \tag{1}$$

where τ is time to destruction; T is a temperature of tests (whether exploitations of construction); τ_0 ~10^{-13} sec - a period of thermal vibrations of atoms; k - Boltzmann's constant; U_o - energy of activating; γ - an activating volume.

Mentioned equation (1) miraculously confirmed experimentally, allowed to describe kinetics of destruction of enormous amount of solids - from metals and alloys to the non-metals, polymers, compos and even wood in the wide ranges of levels of loading, durability and temperatures [2, 3, 5, 9]. Experimental tests on the bases of 100…1000 hours with the help of equation (1) allowed to forecast the resource of constructions for extreme external (high or subzero temperatures – 100 K…0,6 Ts, radiation streams, non-stationary loading) environments to 10 000…100 000 hours. However, the narrow point of mass application of equation (1) was a necessity for every new construction material, or even to the change of his structure, thermal treatment, flowage, radiation loading – experimental determination of energy of activating of U_o and activating volume γ. It is bulky enough procedure that costs considerable charges and occupies long time - from one month to year and anymore. Much criticism authors (1) got for impermissible - from the point of view of phenomeno logical presentations of mechanics of destruction (and absolutely possible from position of synergetics!) - coincidence of values of energy of activating of destruction of monoatomic unhurmony chain let of atoms (level of A - N) with the analogical parameter of macro level - energy of activating of destruction of macro standard (levels Me and Ma). By us [9-15] it was suggested to assume in the sinergistical model of destruction, that in an activating volume under the action of the external temperature-power loading

takes place in time gradual synchronization of oscillators is a kinetic phase transition - from complete chaos (height of chaos $\lambda \to 1$) [16-17] - to practical complete efficiency (height of chaos $\lambda \to 0$) (Fig. 2). This postulate allowed to explain the coincidence of energy of activating of destruction on A, N and Ma (atomic, nano- and macroscopic) structural levels, and also to put and successfully untie plenty of new tasks of mechanics and physics of destruction. For example, to get a theoretical formula for the estimation of energy of activating of BCC and FCC metals and their alloys.

Will consider probability of destruction of model object of level A - unidimensional unharmony chain of atoms under the action of the external loading.

In accordance with presentations, developed Y. Frenkel [4], probability of destruction of chain is identical to probability of overcoming of barrier in time unit even one of oscillators:

$$W = \frac{1}{\tau_{fl}} \cong \frac{1}{\tau_0} exp\left(-\frac{E_{fl}}{\kappa T}\right)$$

where τ_0 is a period of fluctuations of oscillator.

Probability of destruction of chain grows at the increase of the external loading and temperature. Then:

$$\lim_{T \to T_s} W = \lim_{T \to T_s} \frac{1}{\tau_0}\left(-\frac{U_0 - \gamma\sigma \pm \beta\sigma^2 \pm ...}{kT}\right) \cong \frac{1}{\tau_0}\exp\left(-\frac{U_0}{kT_s}\right)$$

On the other hand:

$$\lim_{T \to T_s} W \Rightarrow 1$$

what allows to get approaching of prof. Grabar [9-11], it is got from the sinergistical model of over jump the nano cluster of the synchronized atoms of potential barrier in high U_o:

$$U_0 \cong kT_s \ln\frac{[1]}{\tau_0} \tag{2}$$

4. Theoretical estimation of activating energy of ensemble destruction of chains (level of N) of destruction in the conditions of uniaxial tension and limit plasticity

For research of longevity of solids in the wide interval of temperatures and levels of stresses of their destruction it is possible to examine as one of types of solid phase reactions with characteristic Arrhenius dependence of speed from a temperature [3-5].

Assumption of model: will present the activating volume of highly excited crystal in the state of pre-destruction of unharmony chains superposition. The system of oscillators in the conditions of rampage is synchronized, in other words there is a phase transition "disorder - order" (from the height of chaos $\lambda \to 1$ to $\lambda \to 0$). Probability of jump of the activated complex in time unit over the potential hurdle of U_0 equals [9]:

$$W \cong \frac{kT}{h} \exp\left(-\frac{U_0}{kT}\right)$$

where h is Planck's constant; $h/k \approx \tau_0$.
At $T \to$ Ts

$$\lim_{T \to T_s} W \Rightarrow [1]$$

from where:

$$U_0 \cong kT_s \ln \frac{[1]}{\tau_0} \tag{3}$$

That is similarly to correlations (2) for the structural level of A. As a result, from (3) it is possible to get engineering formulas for the estimation of energy of activating of destruction of the difficult systems. Using of the harmonious approaching of Einstein [9] allows to get:

$$U_0 = kT_s \ln\left(\frac{1}{2\pi a_0}\sqrt{\frac{rE}{\rho}}\right) \tag{4}$$

where ρ is a density.
Similarly, from approaching of Debye as a result we have:

$$U_0 = kT_s \ln\left(\frac{k\theta_d}{h}\right) \tag{5}$$

where θ_d is the Debye temperature.

Dependences (3)-(5), as development of sinergistical model of deformation and destruction of construction metallic materials, in the linear approaching of deformation of electrostatic charge pattern is allow obtain dependence of temperature of melting on external tension:

$$T_s(\sigma) \cong T_{s0}\left(1-\frac{\sigma}{E}\right) \tag{6}$$

For the case of compression ($\sigma = -p$) the temperature of melting must be increased:

$$T_s(p) \cong T_{so}\left(1+\frac{p}{E}\right) \tag{7}$$

What found experimental confirmation in works of Grigorovich [19]

On Fig. 4 the results of comparison of calculations (6)-(7) with experimental data [3, 5] of activating energies for ten BCC and HCC metals are shown. Deserves attention circumstance that experimental values of U_0 [5] got from processing of experimental data of the protracted durability of macro standards, and theoretical formulas - from the condition of the temperature loading of the system of unharmony chains. The high degree of coincidence of "mechanical" and "temperature" values of energy of activating testifies to power similarity of processes of melting and mechanical destruction that was shown before from other positions in works [2]. On the other hand, coinciding of U_0 of elementary event (destruction of unharmony chain - (2)) and macrosystem (destruction of macrostandards) (Fig. 6) confirms adequacy of the offered synergistical model of destruction.

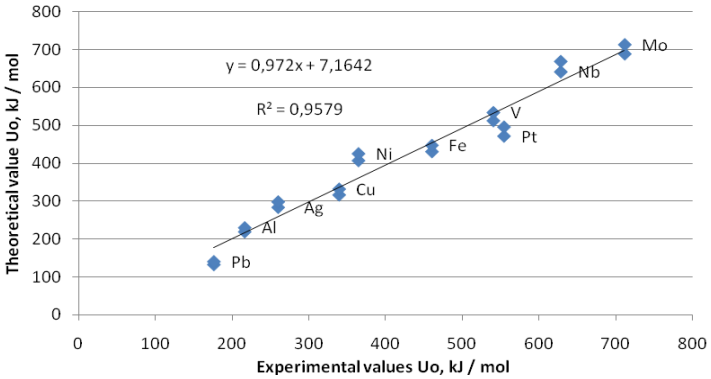

Fig. 4. Theoretical (synergetic model) and experimental values of the activation energy of destruction BCC and FCC metals (Comparison U_o (approaching Debye and Einstein) with experimental data)

5. Synergistical model of destruction and estimation of firmness of activating energy

It is experimentally set that activating energy of destruction is not sensitive to the change of vector of the metal state. For example, change on a few orders of content of admixtures, closeness of distributions, orientation of single-crystals, large doses of irradiation et cetera in most cases change energy of activating no more, than on 2...4 % [3, 5], that especially strikes on a background the substantial (within the limits of order) change of mechanical descriptions. In a table 1 experimental data over of firmness of activating energy are brought for aluminum and his alloys. Until today this experimental fact did not find a due of analytical generalization.

Table 1
Experimental values of rejection of energy of activating attests on of long duration durability of standards from aluminum [5]

#	In-out parameter	Boundaries of change	Rejection of activating energy $\frac{\Delta U_0}{U_0}\cdot 100\,\%$
1	Admixtures of copper	0…4 %	≤ 4 %
2	Admixtures of magnesium	0…4 %	≤ 4 %
3	Admixtures of zinc	0…10 %	≤ 2 %
4	Changes of orientation of single-crystals	[111]…[100]	≤ 2 %
5	Annealing	573 K…873 K	≤ 5 %
6	Rolling is without annealing	0…90 %	≤ 1 %
7	Neutron irradiation	$0\ldots 10^{27}$ ion /m^2	≤ 8 %

Mentioned above correlations (4)-(5) allows to estimate analytically the possible limits of rejection of activating energy at the change of vector of the state of metal. Thus, from approaching of Einstein (4) at T_s = *const* it is possible to get:

$$\Delta U_0 = kT_s \ln\left[\frac{\alpha_+}{\alpha_-}\left(\frac{\rho_+}{\rho_-}\frac{E_+}{E_-}\right)^{0.5}\right] \tag{8}$$

where "+" fit to the maximal, and "-" fit to the minimum value of parameter. Numeral data show [9], that the maximally possible range of variation of parameters does not exceed:

$$\frac{a_+}{a_-} \le 1{,}2; \quad \frac{\rho_+}{\rho_-} \le 1{,}2; \quad \frac{E_+}{E_-} \le 5,$$

what gives a maximum rejection to energy of activating $\Delta U_0 \le kT_s$
At the same time mean value of energy of activating from (3)-(5) at $\tau_0 \approx 10^{-13}$ sec equals:

$$U_0 \cong 30kT_s$$

Thus, change of grid constant on a 20 %, alloy density on a 20 %, module of resiliency on 400 % in accordance with the above-mentioned correlations, results in the change of energy of activating only on a size:

$$\left|\frac{\Delta U_0}{U_0}\right| \le \pm 1{,}6\%$$

that fully comports with the results of experimental researches [3, 5], partly driven to the table 1.

6. Loss of firmness of Uo at the cyclic loading and local excitation of nanocluster.

Without regard to unique firmness of activating energy and its brilliant confirmation in approaching of prof. Grabar (2), in transition there is a sharp loss of firmness (Fig. 5) to the cyclic loading. Our analysis of experimental data of tireless destruction of plenty of brands of steels, cast-irons, heatproof alloys, alloys of aluminum, tungsten, molybdenum, copper and other showed that:

$$\frac{U_0^y}{T} = \frac{U_0}{\beta T} \Rightarrow \beta = \frac{U_0}{U_0^y}$$

It allowed within the framework of sinergistical model destruction and self-organizing of nanoclusters to offer the hypothesis of local excitation that is confirmed by experimental data of the tireless, protracted and static durability. On Fig. 6 it is schematically shown that for the excited state of nanocluster the activated jump takes place not from the power level of kT, and from the power level of βkT. Then time of tireless destruction:

$$\tau = \tau_0 \exp \frac{U_0 - \gamma'\sigma}{\beta kT}$$

Thus we consider a thermally activated jump of the excited nanocluster over the ordinary hurdle of $U_o \cong 30kT_S$ and firmness of energy of activating is kept! Find the parameter of local excitation from the analysis of experimental data of

tireless destruction of plenty of brands of steels, cast-irons, heatproof alloys, alloys of aluminum, tungsten, molybdenum, copper and other, that gives:

$$\frac{U_0^y}{T} = \frac{U_0}{\beta T} \Rightarrow \beta = \frac{U_0}{U_0^y}$$

Experimental values β for BCC (alloys of iron) and HCC (alloys of aluminum) of metals in the wide range of temperatures of loading and terms of fatigue tests give $\beta \in [1...230]$. Thus for the indicated alloys (more than 2000 curves of tiredness) the condition of automodel is got:

$$\frac{\beta T}{T_s} \cong 0.55...0.65$$

In other words, activated jump of well-organized self-organized nanocluster at the cyclic loading at any external temperature it takes place from the power locally excited level $\beta T \cong (0.55...0.65)Ts$

where T is a middle temperature of standard, βT is a temperature of nanocluster.

Why do not these local excitations register one self experimentally? A middle temperature that even in the conditions of multicyclic tiredness can rise on 10-20 ^{o}C.

From approaching of prof. Grabar the built model of the phenomenon of tireless destruction, as formation of the locally excited zone in a time of $10^{-7}\ldots10^{-8}$ sec, that is a sufficient condition for the activated jump of nanocluster of self-organized atoms with the height of chaos $\lambda \to 0$ over the potential hurdle of U_o and origin of fatigue crack. Sagging of imaginary activating energy at tiredness is shown on Fig. 5, and is turn over to the proof value of energy of activating introduction of coefficient of excitation of βkT is shown on Fig. 6.

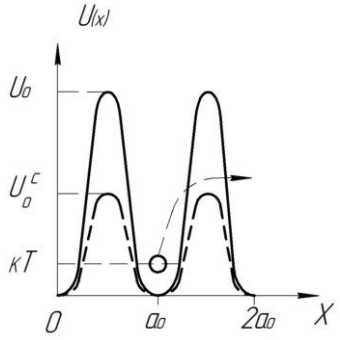

Fig. 5. At the cyclic loading over a proof parameter is energy of activating - loses firmness. Where is reason of contradiction?

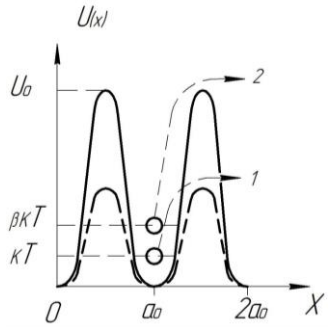

Fig. 6. Energy of activating did not lose firmness - a well-organized nanocluster in a time of $10^{-7}\ldots10^{-8}$ sec passed to the new energetically level $\beta T \cong (0.55...0.65)Ts$

7. Loss of firmness of Uo at the cyclic loading and local excitation of nanocluster.

On Fig. 7 the typical kinetic diagram of height of fatigue crack (diagram of Perice) is shown. The problem of minimum activating volume in physics and mechanics of destruction of metallic materials is known 40 more than. From different positions tried to solve this task S .Katsanda, V. Ivanov, Gurevich, A. Shanyavsky, A. Ioffe, et al. As a result from the sinergistical model of destruction, it is shown by us, that a characteristic cross-correlation radius in the unharmony ensemble of oscillators has an order of size:

$$\vec{r} = \frac{\vec{dr}}{d\tau}\Delta\tau$$

Id est has an order of size of product of characteristic speed of indignation on characteristic time of co-operation of this indignation with the synchronized ensemble of oscillators. It is shown on enormous experimental material, that two values of characteristic speeds of transmission of indignations - resilient waves of S in the atoms chain and resilient waves of C in the collectivized electrons of metal give two values - minimum and maximal are estimations of proof height of fatigue crack for one cycle of fatigue load:

$$\delta_{\min} = S^*\tau_0 \approx \pi a_0 \ldots 2\pi a_0 (10 \ldots 20)\overset{o}{A}/cycle$$

$$\delta_{\max} = C\cdot\tau_0 = 3\cdot 10^{8}\cdot 10^{-13} = 3\cdot 10^{-5} m/_{cycle}$$

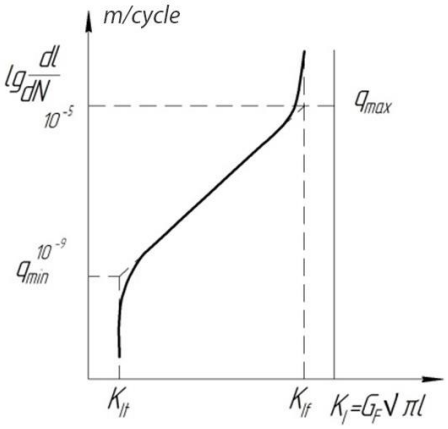

Fig. 7. Typical kinetic diagram of tireless destruction

Comparison of values $\delta_{\min}$ and $\delta_{\max}$ with the special points on the kinetic diagrams of tireless destruction $q_{\min}$ and $q_{\max}$ shows a complete coincidence of its for the wide class of construction materials - steels, alloys of aluminum, magnesium, titan, copper and others like that. It confirms the hypothesis of

sinergistical model of destruction also, as a gradual process of synchronization of unharmony of structural units on different structural levels. Self confirmation of ideas about the collective jump of nanocluster of oscillators in an activating volume allows attaining substantial progress in the design of dynamic processes of kinetics of destruction, as to the cascade of the phase passing to different structural levels as "disorder - order". From a moment the origin of microcracks the process of destruction is not only localized but also shows up - from credible to actual.

8. A management of nanochaos and "eternal" constructions.

On Fig. 8 dependence of the relative stage of longevity of construction with the crack N_p to general longevity N_f (from data of prof. A. Shanyavsky [18]) is shown. As result from Fig. 10, in a low-cycle area (N_f ~1000…50000) the part of cycles of construction with the crack N_p is ~ (0,5…0,95)N_f. Unfortunately, it localizes and shows the crack of low-cycle fatigue already on the early stages of exploitation, and does not give chances repeatedly to "return the local volumes of nanostructural level to chaos", as it was before localization of crack. Actually, a basic conclusion and discovery of sinergistical model of destruction of constructions consist here in - on the stage to the activated collective first jump to turn an activating volume from the state with the height of chaos $\lambda \to 0$ ("order") to the state with the height of chaos $\lambda \to 1$ ("chaos") - Fig. 2. And, as result from Fig. 8 and Fig. 9 for σ/σ_B ~ 0,3 (30 % of the maximal loading) part of resource without localization of crack can reach 95…97 % from general resource.

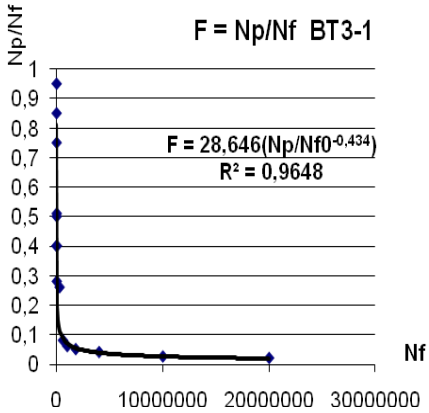

Fig. 8. Relative longevity of construction with the crack of N_p to general longevity from general longevity of N_f

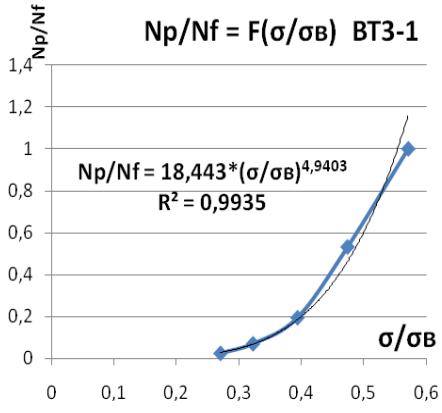

Fig. 9. Dependence of relative longevity from the relative level of loading for titanic alloys (from data [18])

And under such loading it may periodically to return chaos in nanovolume, or to destroy an order (synchronization) in it. The modern theory of phase transitions

sets the enough patterns of destruction of order - by the thermal, magnetic, ultrasonic and other fields, that destroy a distant order in superconductivity, superfluidity, magnetized, nonlinear optical systems, thermal sells of Benar et al strongly excited systems, that distant from an equilibrium, thus physical systems of various physical nature where the coherent states appears.

Exactly from this position superresponsible constructions in the extreme terms of loading (high temperatures, aggressive environment, highly intensive radiation streams) can not in principle be non-expendable (projects: "SHUTTLE", "Konkord", "TU-144" were unsuccessful exactly from this position). And vice versa, for constructions from $\sigma/\sigma_B \sim 0,3$ (if such low level of loading in principle it is possible to attain) a sinergistical model assumes "eternal" constructions – for example, after 50-70 % of resource using to destroy an order in nanostructures, not giving to be realized to the collective jump synchronized ensemble.

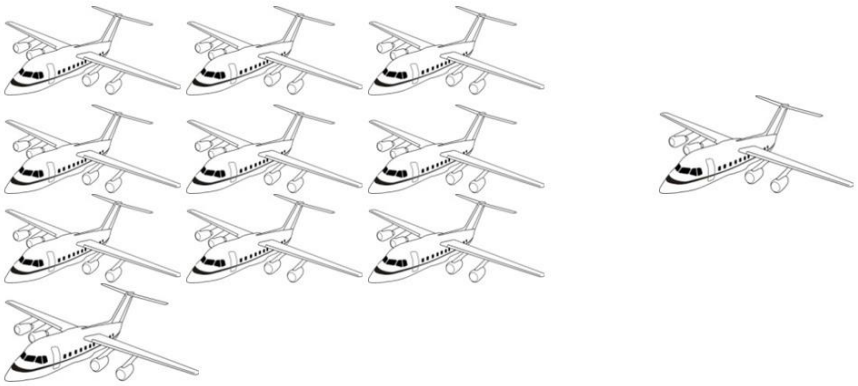

Fig. 10. In the conditions of management nanochaos: a 1 airplane for $200 million or 10 airplanes for $100 million each?

Conclusions

1. Offered sinergistical model of destruction of construction metallic materials, as stochastic nonlinear open system, that under the action of the external temperature-power loading passes a difficult evolution - cascade of kinetic phase transitions "disorder - order" and "order - disorder" on all 5-и structural levels - from atomic (A) to macroscopic (Ma).
2. Given model allowed to get theoretical dependences of activating energy of destruction, as heights of potential barrier that collectively overcomes the synchronized (self-organized) unhurmony ensemble of oscillators in nanovolumes (level N) after a phase transition "disorder - order".
3. Experimental confirmation of this hypothesis is got for the row of BCC and FCC metals and their alloys.

4. On the basis of sinergistical model and its experimental confirmation new conception of substantial increase of resource and reliability of constructions is offered – periodic force destruction of well-organized nanostructures (stage to activated collective jump over the potential barrier U_o), id est a force phase transition "order - disorder" - from the height of chaos $\lambda \to 0$ to complete chaos $\lambda \to 1$.

Future researches must be concentrated on the decision of next tasks:

1. By the methods of molecular dynamics to build the quantitative models of formation of order in nanoclusters and its destruction.
2. To build the quantitative models of influence on destruction of nanoclusters of order:
   - increase temperatures;
   - "chaotic" modes temperature-power, magnetic, gravitational, electro-dynamic loading, large angular accelerations (rotary presses);
   - the regular and chaotic acoustic field;
   - non-stationary temperature waves with the set gradient;
   - nonlinear-optical laser irradiation and others like that.

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