Fracture Kinetics of Aluminum Alloys Sheets by Taking Into the Account the Pulsing Load.

M.Chausov[1,a], V.Hutsaylyuk[2,b], E.Zasimchuk[3,c], A.Pylypenko[1]

[1] National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine

[2] Military Technical university, Warsaw, Poland

[3] Institute of Physics of Metals NAS of Ukraine of G.Kurdyumov, Kyiv, Ukraine

[a] mich@nubip.edu, [b] vhutsaylyuk@wat.edu.pl, [c] eezas@imp.kiev.ua

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Abstract. *The* ***basic laws of a straining and fracture of sheet aluminum alloys at dynamic non-equilibrium processes are installed.***

Introduction. At the present time it is installed that at dynamic non-equilibrium processes interacting of materials structural elements with electromagnetic, ultrasonic, power and other power fields activates in materials self-organized processes with formation new existential dissipative structures providing essential change of materials initial mechanical properties [1,2].
The great interest for researchers is represented the boundary conditions of structure self-organising of materials at dynamic non-equilibrium processes at which mechanical properties as much as possible increase at macrolevel or sharply decrease, up to material final fracture.
A material non-equilibrium condition in states of uniaxial static extension it is possible to attain various methods, for example, by application of high compressing loadings at the raised temperature, elektrostimulated heating by currents of high density, by affecting of electromagnetic and shock ultrasonic oscillations, etc.
The new aspect of mechanical tests presented in works [3…6] is developed for implementation of dynamic non-equilibrium processes on department of mechanics, strength of materials and building of National University of Life and Environmental Sciences of Ukraine.
Processes of a straining and fracture of materials at pulsing load are investigated as a part of mechanical system which represents the elementary statically undefined construction, in an aspect of simultaneously loaded three parallel elements, the central specimen and two symmetric different cross-section specimens-companions («fragile tests»), made from hardened steel 65G or U8A according GOST. At a loading of the given construction specimens-companions are fractured (at the set loading level on the specimen or its set deformation) and pulsing feeding into of energy in a material of the investigated specimen is carried out.
As a result of the smooth cylindrical specimens spent before mechanical tests from various materials it is installed that at dynamic non-equilibrium processes almost all plastic materials manifest propensity to short-term plasticization with a simultaneous "abnormal" loss of strength at the expense of dissipative structures formation in the form of the localised strips, is volume connected on various scale levels [4 … 6].
By method transmission electronic microscopy it is installed that for different materials width of these it is thin-flat structures changes from 0,01 to 7 μm.
The purpose of the present work is determination of straining and fracture laws of sheet aluminum alloys at dynamic non-equilibrium processes.

Results of research. The experimental technique is analogous to [4 … 6].
Researches is carried out on planar specimens from aluminum alloys D16 and 2024-T3 in the width 10 mm and thickness 1,5 and 3 mm.
About structurization under load, it is possible to qualify on a superficial landform which is fixed directly in the deformation process. In the given research on a working part of specimens by means

of special glue PASCO Fix pasted a monocrystal foil in the thickness 200 μm with orientation <100> {001} (sensor), made of a monocrystal of high purity aluminum by means of electrospark cutting with the subsequent electropolishing. Mechanical characteristics of aluminum monocrystal with orientation <100> {001} a yield stress σ_y=20 MPa, extent of deformation before fracture ε_p=63 %.

Development of a monocrystal superficial landform investigated directly in the course of a straining by removal of a video film by means of a microscope and camera Casio Exilim Pro EX-F1 with frequency to 1200 fps.

On fig. 1,a results of pulsing load influence on a straining process of aluminum alloy D16 at a difficult under-load operation (static extension – pulsing load) are presented.

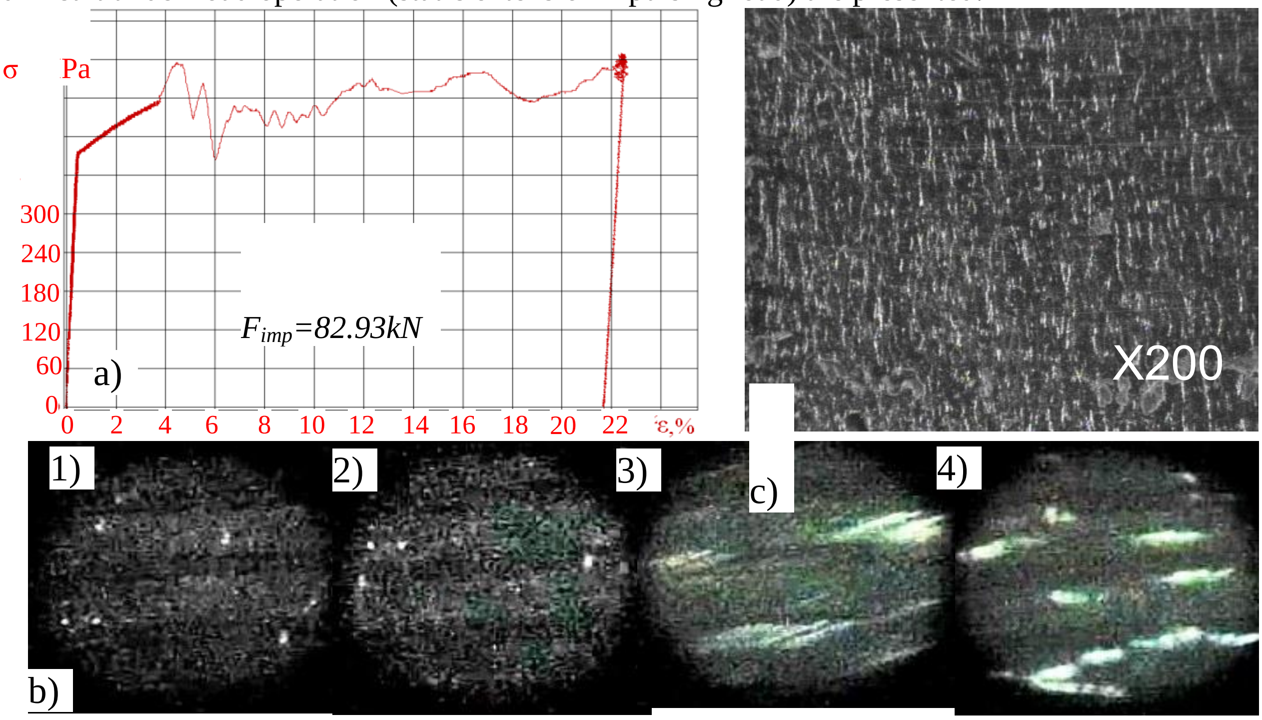

Fig. 1. The deformation diagram of alloy D16 taking into account pulsing load – a; kinetics of a landform change of a monocrystal sensor control during pulsing load – b; a landform of a sensor control after pulsing load – c (f=600 fps, d_{area}=0.3 mm)

It is interesting to track landform formation on a monocrystal during dynamic non-equilibrium processes as it can be treated as a superficial trace internal dissipative structures which is formed in a material. Because the monocrystal is rigidly fixed on the specimen, it can change the form in a direction, to perpendicular its surface. It forming inseparably linked with decrease of a monocrystal density (at invariable weight). It is possible, when at sharp receipt from the outside of energy there is an unstable state of a material structure with its further self-organising in the form of structural elements with the lowest density. On fig. 1,b the kinetics of a landform formation of a monocrystal sensor control is presented during pulsing load. At first there are arise microextrusion zones (white points), then these zones are merged and increase. The periodic grid of "heckles" ("hills") is thus formed. On fig. 1,c, for example, the monocrystal landform at the moment of end of dynamic non-equilibrium process is represented. The characteristic structural traces of localisation in microextrusion in the grid form of "heckles" ("hills") are observed. In our opinion, a observed landform is a consequence of formation dissipative structures. Thus, with use of a monocrystal sensor control and high-speed photographing the actual information on formation dissipative, less dense, structures is gained during dynamic non-equilibrium processes.

On fig. 2 influence of the equal intensity pulsing load 80kN, carried out at different preliminary static deformation levels, on process of a straining of aluminum alloy D16 is shown. Due to the data analysis it is possible to draw a leading-out that influence of preliminary deformation on jump of aluminum alloy D16 deformation during pulsing load is essential.

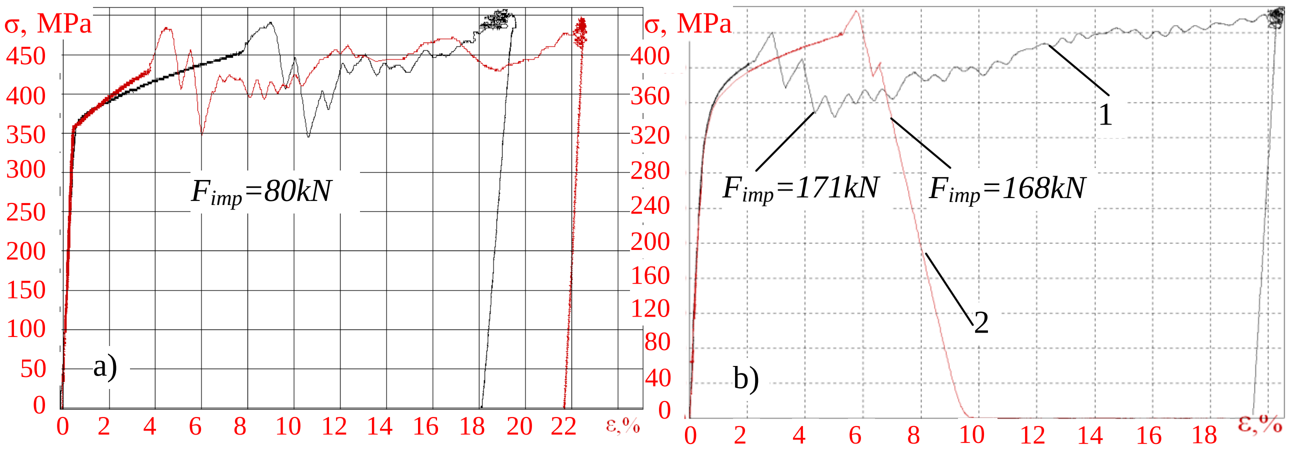

Fig. 2. The influence of preliminary static deformation on a straining of aluminum alloys:
a – alloy D16; b – alloy 2024-T3

On fig. 2,b, for example, as practically at equal pulsing load on mechanical system (~170 kN), but at different levels of preliminary static deformation, the alloy 2024-T3 or it is strongly plasticized (a curve 1), or is fractured (a curve 2) it is shown.

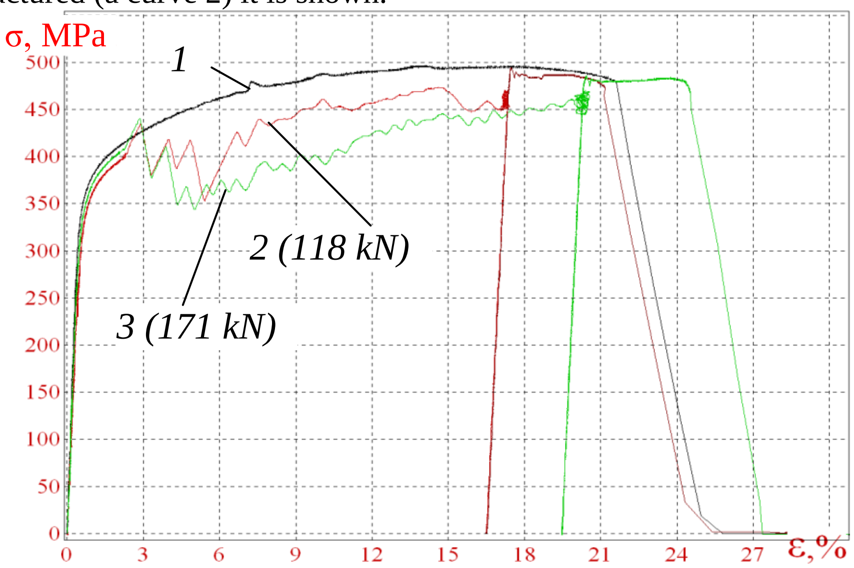

Fig. 3. The influence of pulsing load intensity on straining process of alloy 2024-T3

On fig. 3 other instance of impulse influence on an alloy 2024-T3 is shown. Pulsing load on specimens were put practically at equal level of static deformation, but with different intensity (curves 2, 3). Here, for comparison, curve of deformations of alloy (a curve 1) at "pure" static extension are resulted. After the jumps of deformation which generated pulsing load, specimens completely unloaded and repeatedly statically stretched to fracture. Here it is necessary to pay attention on interesting feature connected with increase of the general plasticity of an alloy in some set range pulsing load (see a curve 3 on fig. 3).
The analysis of experiments shows that for investigated aluminum alloys the mechanism of influence of pulsing input of energy in a material appears similar. There is a concrete range of preliminary static deformation and concrete pulsing load levels, at which mechanical properties of alloys as much as possible increase at macrolevel, and there are analogous characteristics, at which mechanical properties sharply decrease to material final fracture.
The estimation of properties dissipative structures is represented a especiality interest.
Authors offer an estimation technique of dissipative structures propensity to embrittlement due to change of temperature loading conditions of material specimen. For this purpose, after the overshoot of deformation, which generated by process of creation dissipative structure in material at room temperature, specimen completely unload, fill up liquid nitrogen, stand in liquid nitrogen, and then thaw out on air to room temperature and repeatedly statically tension up to their complete separation into parts.

The given researches specially carried out on aluminum alloy 2024-T3, which is not inclined to embrittlement at simple loading mode at low temperatures.
On fig. 4 tests results of alloy of accordingly offered mode (a curve 2) are presented. Here, on fig. 4, for comparison, the resulted curve 1, which corresponds test specifications «static extension – dynamic non-equilibrium process – static extension» at room temperature, and a curve of a straining of a material at "pure" static extension (a curve 3) at room temperature.

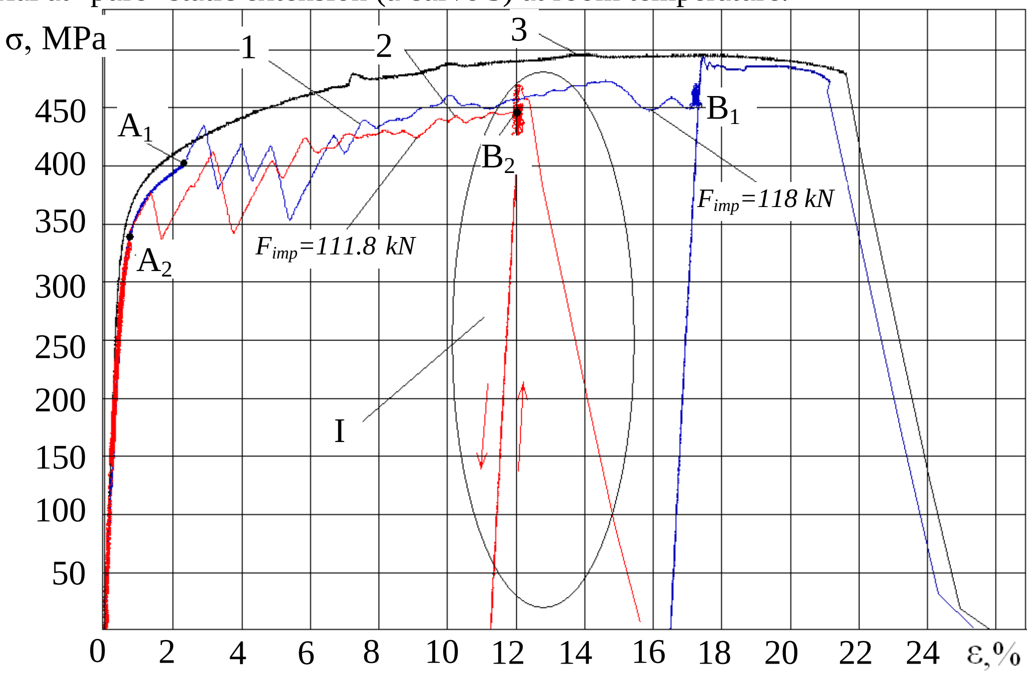

Fig.4. The influence of change of tests temperature on embrittlement dissipative structures in aluminum alloy 2024-T3

The analysis of the gained results shows that change of a temperature load operation bring to embrittlement of dissipative structures in a material. So, the specimen of aluminum alloy at static retension was fractured is almost fragile (see area I on curve 2, fig. 4) at much smaller common deformation, in comparison with static extension.
In this case influence of additional compression temperature stresses on increase in failure volume in dissipative structure is effectively manifested.
The gained experimental data testify about depending on volume dissipative structures, which was formed in material under different conditions of a thermo-power loading at dynamic non-equilibrium processes, mechanical properties of a hybrid material (a basis, dissipative structure, interlayers) at the further static extension can essentially differ from mechanical properties of a initial material.
Earlier by authors it has been installed [6] that at multi pulsing load of smooth cylindrical specimens from stainless steel and aluminum alloy D16 at room temperature, at the subsequent static loading at same temperature, materials start to manifest properties quasi-superplasticity during the initial moment of a straining. This effect is the reason for formation at dynamic nonequilibrium processes of thin-strips (less dense) dissipative structures.
In the present work it is experimentally installed that similar effects are manifested in sheet aluminum alloys even at one-shot pulsing load. On fig. 5,a,b,c the results of alloy D16 tests are presented in increasing intensity pulsing loads. And the extent of initial static deformation at which were carried out pulsing loads was almost equal (3.92…3.98 %). Comparison of tests results of alloy D16 at static loading and a difficult load mode, taking into account pulsing load, is shown on fig. 5,d.

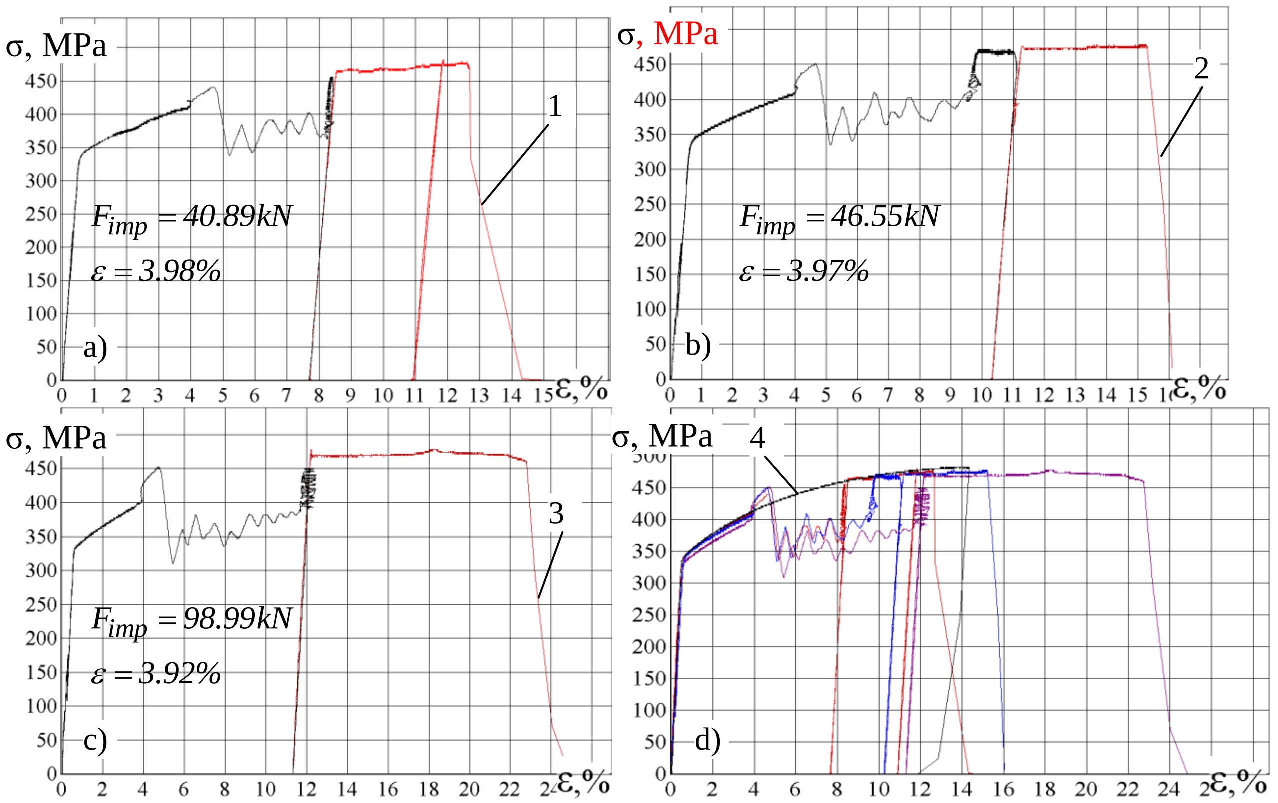

Fig.5. Curves of deformations of alloy D16 in increasing intensity pulsing loads (1…3) and at static extension (4)

On fig. 6,a,b,c analogous tests results of alloy 2024-T3 are presented. Level of preliminary static deformation, at which were carried out pulsing load samples, changed within 1.33…2.05 %.

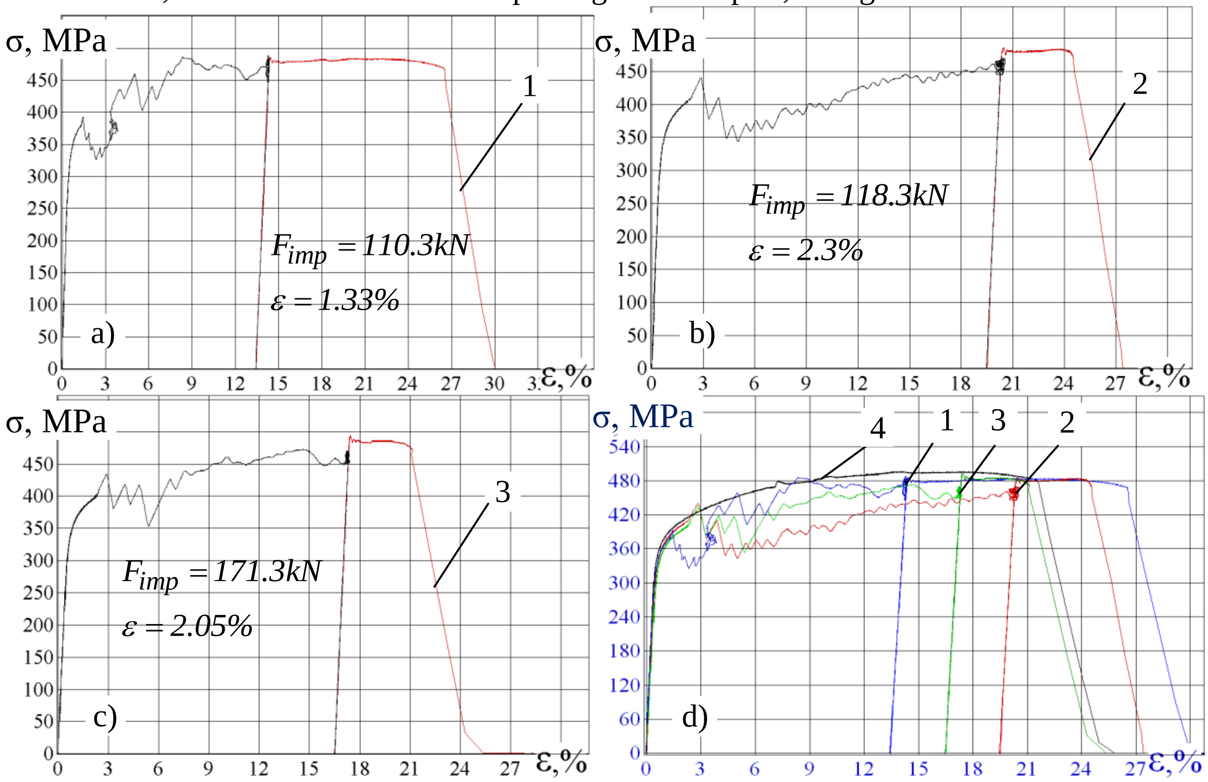

Fig.6. Curves of deformations of an alloy 2024-T3 at increasing intensity pulsing loads (1 … 3) and static extension 4

Comparison of tests results of alloy 2024-T3 at simple and difficult modes of a loading, is shown on fig. 6,d. We note that the trend of developing process of yielding plateaus in alloy 2024-T3 after one-shot pulsing loads remains. However, their slowness at increase in intensity pulsing loads, in comparison with alloy D16, on the contrary decreases. Probably, it is corresponded by that there is a ceiling of an alloy deformation at such difficult loading mode. The increase in making deformation at a formation section dissipative structures in a material, automatically leads to decrease of making deformation at static retension. On the other hand, at pulsing loads the process of a material self-organising so difficult that it is impossible to deny a fact, that change of an initial plastic deformation level at which occurred pulsing loads, could lead to similar result.

Authors offer physical and mathematical validation of developing process of yielding plateaus of various extent at one-shot pulsing loads of aluminum alloys.

From the physical point of view obviously that the given process is directly connected with presence in a material of volume of neogenic thin-trips (less dense) dissipative structures. And, as all tests were carried out at room temperature, two basic mechanisms which are inherent in a superplastic deformation – diffused creep and transgranular slippage in this case are absent. Obviously as well that in the course of pulsing energy input in a material, thin-strip dissipative structure embraces considerable volumes (blocks) of the material which size on usages exceeds a size of initial grains.

In it, probablly, is the basic difference between process of superplastic deformation and the phenomenon of developing process of yields plateaus consists at pulsing loads materials at room temperature.

At a superplastic deformstion the basic mechanism is transgranular slippage, in an investigated case – slippage between material blocks. As consequence, extent of yield plateaus of a material at pulsing loads much less than the common deformation of a material at superplasticity.

On fig. 7 presented the scheme of process and real dissipative structures of materials after pulsing loads.

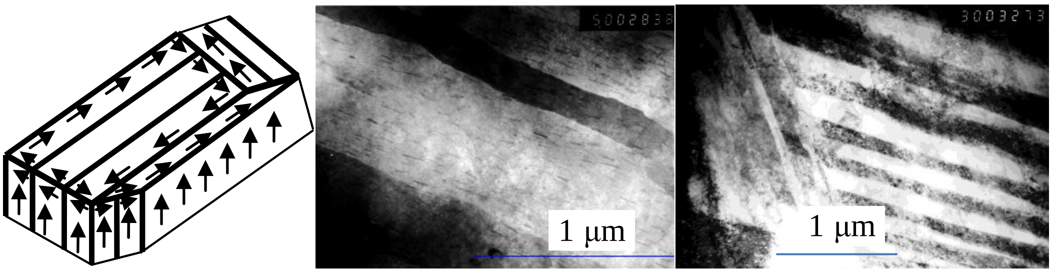

Fig.7. The scheme of process and real dissipative structures of materials after pulsing loads

The revealed analogy in a straining processes of materials at superplastic deformation and after pulsing loads allows to use the general approach of the theory of superplasticity for extent of yield plateaus after pulsing loads sheet aluminum alloys.

This approach consists that within the limits of a hypothesis of a uniform curve it is possible to express dependence between intensity of stresses and intensity of deformation speeds by a relationship through nonlinear function of shear viscosity μ which generally depends on chemical χ and phase composition θ, temperature T and velocity of deformation $\dot{\varepsilon}_i$ (or impressed stresses σ_i), a size of structural components L or and Ω other parameters p_i:

$$\mu = f\left(\chi, \theta, T, \dot{\varepsilon}_i, \Omega, p_i\right). \qquad (1)$$

For simplicity of the analysis we will be restricted to scheme of uniaxial extension, that is that scheme at which effects of developing process of yield plateaus of sheet materials are experimentally revealed at pulsing loads.

Analogously to the aforesaid the concept of effective shear viscosity in the course of formation dissipative thin-strip structures in a material is inducted:

$$\mu_{imp} = \frac{\sigma_{imp}}{\dot{\varepsilon}_{imp}}, \qquad (2)$$

here σ_{imp} – static stress at which are carried out pulsing loads; $\dot{\varepsilon}_{imp}$ – average velocity of material deformation in the course of formation dissipative structures in a material (%/c) (sections of an "abnormal" loss of strength of materials in the course of pulsing loads).

It is obvious that the value of effective shear viscosity μ_{imp} of material less, the much volume of neogenic thin-strip structure in a material. Therefore, if to include the similar characteristic for the description of yield process of materials on yield plateaus which are manifested at the further static extension μ_{stat}, that it is possible to establish nonlinear interdependence between magnitudes μ_{imp} and μ_{stat}:

$$\mu_{imp} = K^{a} \mu_{stat}\,, \tag{3}$$

here – K, a dimensionless constants of materials for the given process.
As a first approximation for an estimation of yield plateaus after pulsing loads it is possible to use linear dependence between μ_{imp} and μ_{stat} ($a=1$):

$$\mu_{imp} = K \mu_{stat}\ . \tag{4}$$

In more evident aspect, the extent of yield plateaus $\varepsilon_{pl.y}$ depending on intensity pulsing load it is possible to present in view:

$$\varepsilon_{pl.y} = \varepsilon_{imp} \frac{\sigma_y}{\sigma_{imp}} exp\left(-\frac{\varepsilon_{pr}}{\varepsilon_{imp}} \right)^{a}, \tag{5}$$

here ε_{imp} – jump of deformation during pulsing load of material; ε_{pr} – preliminary static deformation at which are carried out pulsing load; a – material parameter, σ_y – yield plateau stress.
On fig. 7 results of comparison of experimental data and mathematical modelling of process for two investigated alloys are presented. The satisfactory coordination of the data is noted.

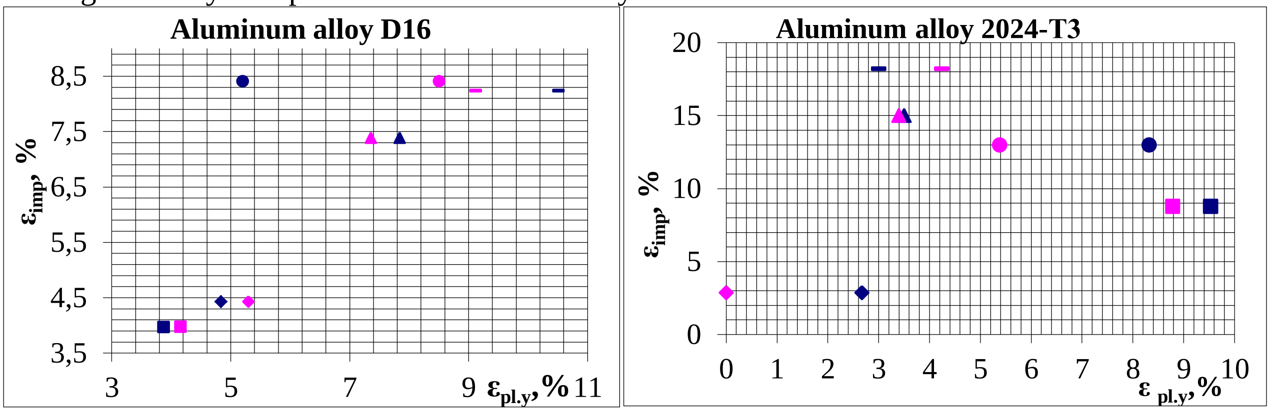

Fig.8.s Dependences between deformation jump (ε_{imp}) in the course of pulsing loads and extent of yield plateaus ($\varepsilon_{pl.y}$): ═, □, ○, ◊, Δ – experimental tributes for alloys D16 and 2024-03, accordingly, ▬, ■, ●, ♦, ▲ – the data counted by formula 5.

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Summary

1. High sensitivity of sheet aluminum alloys to act of dynamic non-equilibrium processes is revealed. It is shown, how depending on level of preliminary static deformation and intensity pulsing loads sheet aluminum alloys or it is strong plasticized or are fractured.
2. The revealed propensity dissipative structures in an aluminum alloy 2024-T3 to considerable embrittlement at change of temperature conditions of loading.
3. The effect of developing process of yield plateaus is experimentally installed at one-shot pulsing loads sheet aluminum alloys. Extent and a site of yield plateaus on deformations diagrams, after pulsing input of energy in a material, with difficulty depends on level of preliminary static deformation at which are carried out pulsing load and their intensity. The physical and mathematical validation of this process is offered.

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