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# INFLUENCE OF PRE-COMBINED LOADING ON MECHANICAL PROPERTIES AND FRACTURE MECHANISM OF ALUMINUM ALLOY 2024-T3

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## ABSTRACT

This paper experimentally investigates the influence of the pre-combined load on the mechanical properties of aluminum alloy 2024-T3. The combine loading is realized by the way of imposing additional impulse load on static component. The basic patterns of deformation mechanisms for static and cyclic loading were analyzed. Based on their analysis an attempt was made to explain the physical processes that are realized in the process of combined load.

**Keywords:** instant impulse load, static load, dynamic non-equilibrium processes, dissipative structure.

## INTRODUCTION

It is now established that the interaction between the structural elements of materials with the external force field of energy initiates dynamic non-equilibrium processes (DNP). This results in a self organization phenomena in the material structure with the formation of its new state-space (dissipative structures), which provide a significant change in the initial macromechanical material properties (Meyers et al.2003; Xue et al.2005; Xue 2006; Xu et al.2008; Andrade et al., 1994)

The great interest present the border state of self-organizing structure of materials at the time of realization of dynamic non-equilibrium process, where macromechanical properties can increase to a maximum or decrease sharply, up to the complete failure of the material

Laboratory setup for realization of dynamic non-equilibrium processes by force effects and mechanical testing methods were developed by Prof. N.Chausov et al. (Chausov et al. 2009; Zasimchuk et al.2009). Processes of deformation and fracture of materials with additional force loading are investigated in the mechanical system. It consists of a statically indeterminate structure, in the form of simultaneously loaded three parallel elements - the central specimen and two symmetrical specimens-satellites (" brittle" specimens), of various cross-sections. Upon loading this construction specimens-satellites are destroyed (at the appropriate level of load or strain) realizes additional force loading impulse (energy input) into the material of the test specimen.

As a result of experimental research using the transmission electron microscopy (TEM), it was found that the dissipative structures have a density less than the density of the base material (Zasimchuk et al.2009). In tests of various classes of materials show a wide margin change of plastic and strength properties of the materials in relation to value of energy (force) impulse, the degree of deformation at which the material is exposed to the impulse influence, amount of additional force loading of the material and change of subsequent temperature conditions of loading.

If additional force loading realized on site until the yield stress of the material, with minimal damage to the material the distribution of the newly formed dissipative structure of the material will be different from the distribution of the material, with a significant level of plastic deformation, when the level of the material damage is much higher. Accordingly, the effects of the influence of the additional force load, carried out at different stages of deformation during the subsequent static and cyclic loading, will be different.

The aim of this work is to investigate the influence of the additional force loading realized on the region of elasticity of the material, the subsequent static and cyclic deformation of aluminum alloy 2024-T3.

## THE METHODOLOGY AND THE RESULTS OF RESEARCH

Mechanical tests were carried out on flat specimens of aluminum alloy 2024-T3 10-25 mm wide and 3 mm thick (Fig. 1) by the method presented in our works (Hutsaylyuk et al., 2012; Chausov et al.,2012; Zasimchuk et al.,2012; Hutsaylyuk et al., 2012). The intensity of the additional force load was within 54 ... = 171kN. Recorded deformation field during and after DNP on the surface of large flat specimens by Digital Image Correlation (DIC), using high-speed camera Phantom v711

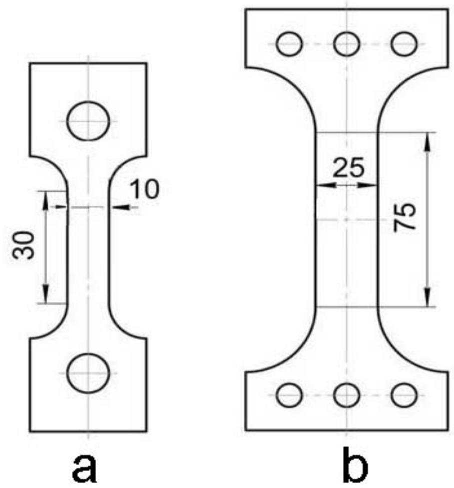


Fig.1 Specimens for testing:
a) small specimen;
b) specimen for research of the deformation field by the method of Digital Image Correlation

First to be analyzed were the results of tests of specimens with width of 10 mm.

Figures 2-4 show some results of these experiments.

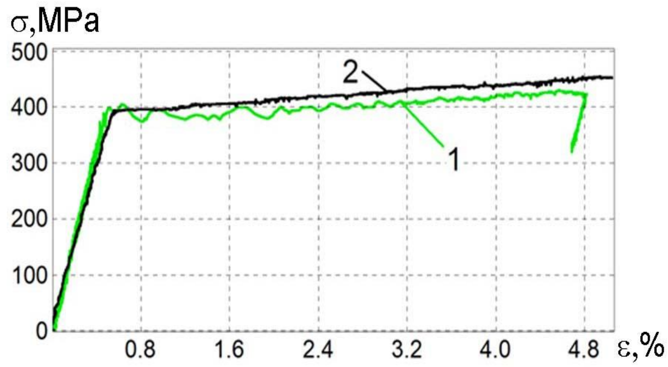


Fig.2 .Strain curves of aluminium alloy 2024 - T3 (specimens width of 10 mm) at different loading conditions:
1 - combined loading ($F_{imp}$=54kN); 2 - tension loadnig

It should be noted that with the additional force loading on the elastic site deformation of the alloy dynamic non-equilibrium processes proceeding in the material, contribute plasticization alloy, which characterizes the decrease of strengthening (Fig. 2). With this high frequency loading alloy (implemented frequency at 1.5 ... 2 kHz) there is a significant change in the structure of the material, according to the results presented in Figure 3 and 4.

In Fig. 3 shows that during the subsequent tensile loading specimen, after the realization of dynamic non-equilibrium processes, the material appears the yield plateau length of about 7%. It is not typical for this alloy. Material destroyed practically without area weakening.

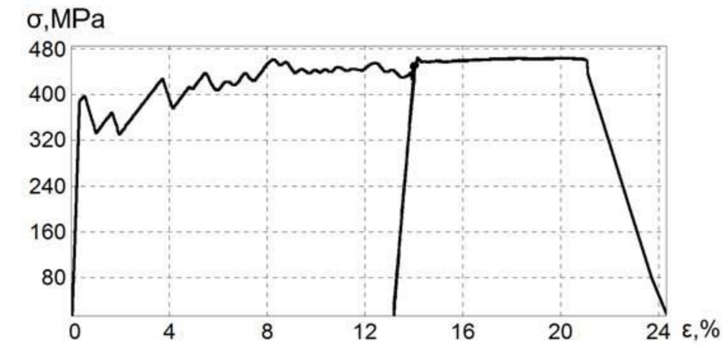


Fig.3 .Yield plateau after additional force loading aluminium alloy 2024 - T3 on the elastic section ($F_{imp}$=108kN)

Another example of the influence of changes in the structure of the alloy deformation processes is shown in Figure 4. With increasing of the velocity tension with 1 mm / min to 10 mm / min aluminum alloy 2024 - T3, in the original state almost immediately softening and destroyed, and the alloy after DNP deformed by the classical scheme (hardening, softening). In this case, it shows a much larger margin of plasticity. Newly formed dissipative structures are less dense, therefore less stronger than the base material. This is due to the fact that the increase in deformation rate leads to an increase of the dynamic yield strength of dissipative structures that can reach the level of strength of the base material. Next, the structure deforms together and as the basic material for dynamic non-equilibrium processes almost hardened its subsequent behavior during deformation is quite predictable.

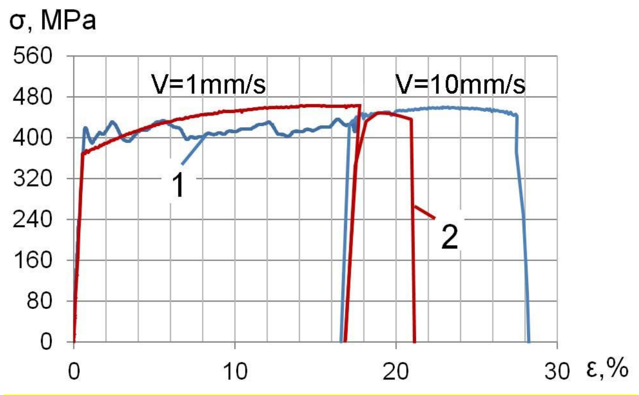


Fig.4 .The effect of the realization of dynamic non-equilibrium processes on the subsequent tensile loading of aluminium alloy 2024 - T3 with increasing loading velocity:
1 - combined loading, 2 - static stretching.

Some of the test results of these specimens are shown in Fig. 5 ... 7. There is confirmed the absence of hardening alloy for realization of dynamic non-equilibrium processes (Fig. 5). Probably the absence of hardening is just one of the characteristics implementation of dynamic non-equilibrium processes in the material. This suggests local changes in the structure of the material, which can be directly associated with significant heterogeneity of the dislocation density in the high-frequency vibrations. In areas with the lowest density of dislocations can occur most intense plastic deformation processes in the formation of a body volume connected to the different levels of scale dissipative structures of lower density and strength.

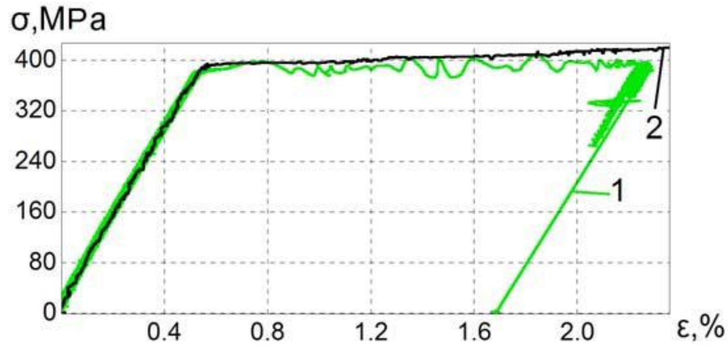


Fig.5 .Strain curves of aluminium alloy 2024 - T3 (specimens width of 25 mm) at different loading conditions:
1 - combined loading ($F_{imp}$=100kN); 2 - tension loading

Results that confirm the delay necking after DNP and increase overall plasticity of the alloy are shown in Figure 6**.**

Special attention should be paid to the results of estimate of the evolution of the deformation field (Fig. 6.7) on the surface of specimens analyzed using the original software package, based on the method of digital image correlation (Berezin 2011, Chausov 2011).

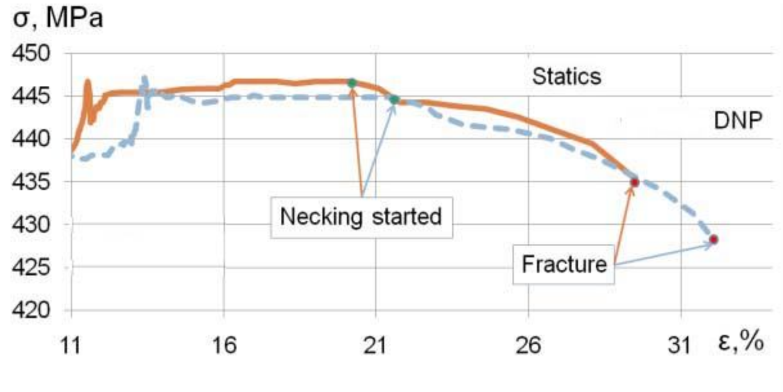


Fig.6. Delay the process of the necking after additional force loading aluminum alloy 2024-T3 on the elastic section

After the realization of dynamic non-equilibrium processes on the surface of the specimen registered a significant heterogeneity of the deformation field (Fig.7).

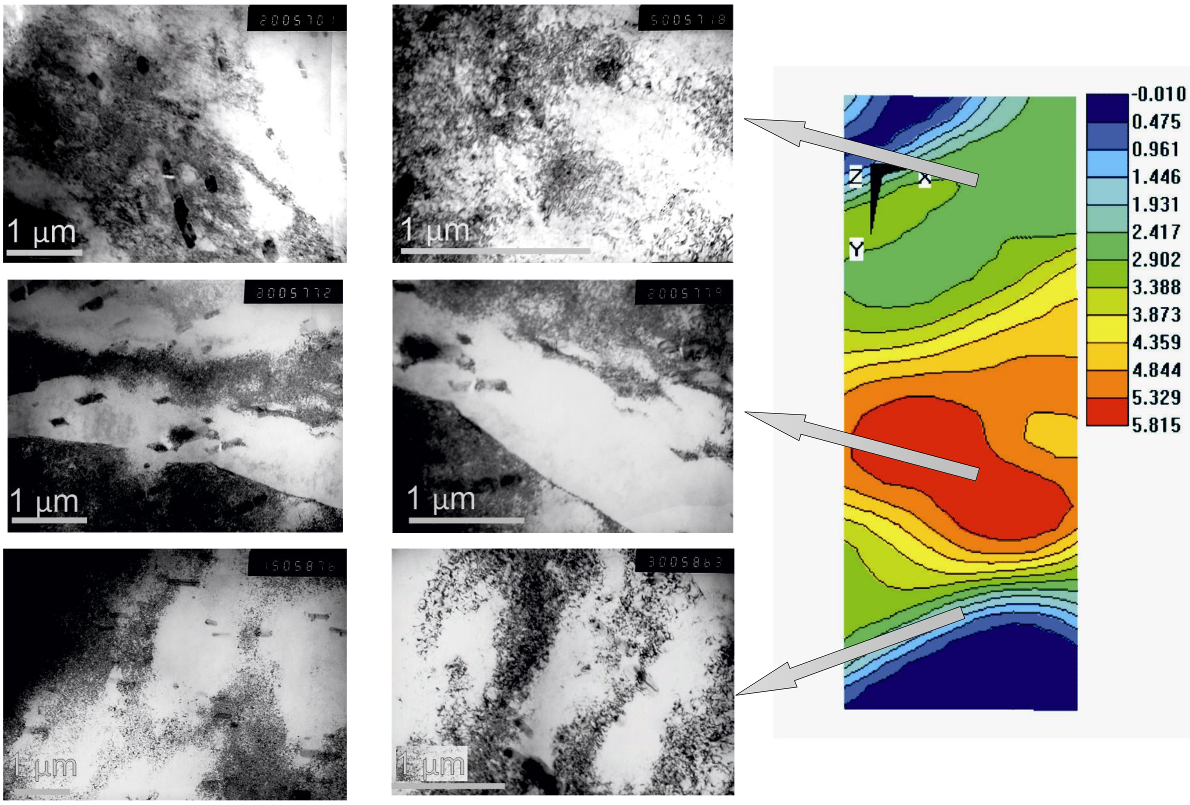


Fig.7. Deformation field on the surface of aluminum alloy 2024 - T3 after additional impulse force loading on the elastic section with the corresponding TEM – structures.

The comparison TEM - structures areas corresponding different levels of deformation confirmed that in the area of maximum deformation to fully implement thin - strips of dissipative structures, contribute to a sharp plasticization alloy. In the rest of specimen marked "white" areas of different sizes with both clear and with blurred boundaries. In some cases the area distributed by several morphologically preserved microbands. It is assumed that the "white" areas are not fully formed stripe dissipative structures and represent a recrystallized grains formed as embryos (microbands and micrograins) and growing in the process of plastic deformation.

Fractografy research carried out on specimens after fracture surfaces combined load and specimens deformed monotonous load to a level corresponding combination. Research performed using scanning electron microscopes Philips XL30/LaB6 and research results are presented in Figure 8.

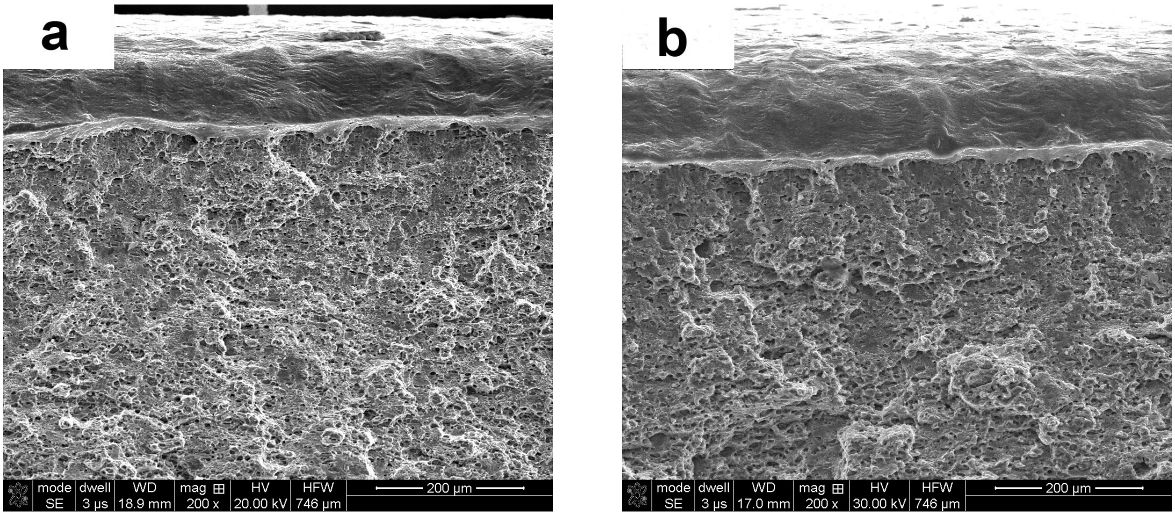


Fig 8. A SEM micrographs illustrating cross-section clad layer of 2024-T3 aluminum alloy specimen: a - the additional force impulse, b - after monotonic loading.

In the analysis of the entire surface Fig.8 for the load of two types of cross section clad layers are similar. There appears to be a noticeable shift along the crystallographic planes of bands visible in the fatigue striations, no significant overall damage to the homogeneity of the layer. The nature of the load does not cause any specific changes are joining layers of material clad layer home. In Fig. 8a and 8b zone looks almost identical.

As mentioned earlier the fracture surface of the base material of 2024-T3 aluminum alloy for different load cases have varied morphology (Fig. 8). With additional force impulse clearly formed band of ridges (acclivity) with fluent passing in the cavity. The monotonic load on a much larger and deeper cavities of irregular shape and size of several grains (Fig. 8b). These elevations in most individual joining the band formed micro areas the size of some grains.

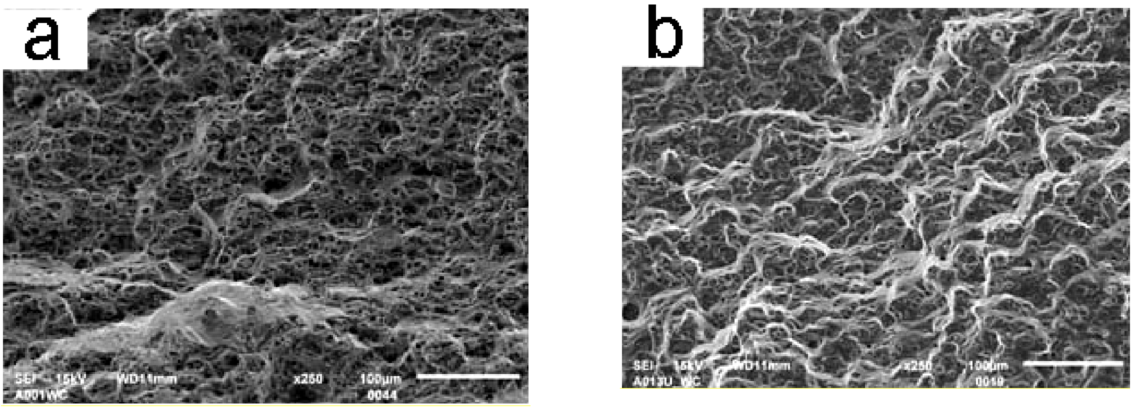


Fig.9 Fracture surface of the specimen after:
a) cyclical load material; b) cyclical load material after previous combined

The surface of the base material fracture Fig.9a after cyclic loading is characterized in general ductile fracture. On the surface, clearly indicated holes in inclusions around which typically larger cavity formed as a result of combining micropores. The surface is characterized by a uniform allocation cavity suggests intergrain character fracture. The presence of traces of fatigue striations on individual facet indicates that the material contains another mechanism of fracture.

When combined load with next cyclic loading the nature of the surface fracture significantly changes (Fig.9b). A characteristic attribute is the presence of comb to break way, reducing the size of the surface cavity. This clearly signals a change of fracture mechanism on mixed. It is characterized by signs of both ductile and brittle mechanisms. Besides the presence of a river pattern on the comb suggests implementing local processes of fracture.

Based on fractografy research can conclude that the previous combined load initiates a complex mechanism of deformation and fracture. The failure is performed simultaneously in at least three areas: the fracture of the material inclusions, local processes of deformation, fracture and grain groups and intergrain.

## CONCLUSION

Established that aluminum alloy 2024-T3 is very sensitive to the dynamic non-equilibrium processes, realized by an additional force loading in the elastic region of the diagram tension.

Structural changes proceeding in the alloy 2024 - T3 at realization of dynamic non-equilibrium processes contribute to a sharp change in the mechanical properties of the alloy in the subsequent static and cyclic loading.

The impossibility to predict the mechanical behavior of the material after the realization of dynamic non-equilibrium processes at different levels of pre-static deformation and varying intensity of the additional force loading makes problematic reliable estimate of durability of the material with a probability of uncontrolled load jumps.

After DNP process a delay of necking in aluminum alloy 2024-T3 in subsequent static tension for 1 ... 5%.

After the DNP precesses of 2 ... 7% increases the degree of local plastic deformation at the points of initiation of material failure in the working part of the specimen.

Preliminary combined load initiates a complex mechanism of deformation and fracture. To clarify the integrity it is necessary to consider the characteristics of the phenomenon of combined load in these studies.

## ACKNOWLEDGMENTS

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