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Modification of the Mechanical Properties of the Sheet Two-Phase High-Strength Titanium Alloy VT 23 Due to Impulse Introduction of Energy

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Abstract

This study shows the effect of the specific impact-oscillatory loading (dynamic non-equilibrium processes) on the variation of the mechanical properties of the sheet two-phase high-strength titanium alloy VT 23. The results of fractographic research are used for interpreting the results of mechanical tests.

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1. Introduction

Aircraft construction requires the use of materials that can withstand the severe pressures of flight at high altitudes. Titanium alloys for industrial use are widely used for aircraft as a material having light weight (density being 60% that of steel), high strength, and excellent corrosion resistance. The authors are actively developing a new line of research in the mechanics of deformable solids, which is associated with the dynamic non-equilibrium processes (DNP) on the variation of the initial mechanical properties of structural materials. A simple and effective method of the DNP implementation is developed, which consists in a high-speed stretching of the material with the superimposition of a high frequency vibration process (several kilohertz) [1–3]. This mode of loading is achieved on a specially modified test setup that consists of two circuits – the external (a load frame of the test setup) and the internal ones. The internal circuit is the simplest statically undefined structure, which consists of three parallel elements loaded simultaneously, i.e. the central specimen and two symmetrical satellite specimens (“brittle samples”) of different cross-section made of hardened steels 65G or U8-U12. When this structure is loaded, satellite specimens are destroyed (for a given load or strain), and extra energy is introduced into the material of the test specimen under the implementation of the above loading process. The analysis of the results obtained on the materials of different classes has shown that transients modes of loading, which are implemented under short pulses of the force uploading characterized by the mass transfer without any dissipation of energy in the classical sense (i.e. conversion of the mechanical energy into heat), allow for the self-organization of new dissipative structures in structural materials, whose physical and mechanical properties are significantly different from those of the original structure [3–5]. In case of loading with a short impulse at a short distance from the surface of the impact, slow diffusion mechanisms of the momentum and energy transfer are still undeveloped. Therefore, the energy of the power pulse is transferred from the macroscopic level to some intermediate mesoscopic level, at which the energy left in the medium is spent on the formation of new dissipative structures. The objective of the paper is to study the effect of the impulse introduction of energy into the sheet two-phase high-strength titanium alloy VT 23 on the variation of its mechanical properties under further static tensioning, and to interpret the results of mechanical tests based on the results of fractographic research.

2. Research technique

The developed and repeatedly tested methods of the DNP implementation under impact – oscillatory loading [1–3] were used in this study to perform tests on specimens from the sheet two-phase high-strength alloy VT 23 with the thickness of 3 mm (Fig. 1).

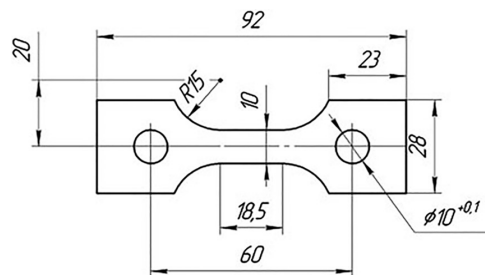


Fig. 1. Test specimen.

The chemical composition of the alloy under study are given in the Table 1.

Table 1. The chemical composition of the titanium alloy VT 23, (%).

Fe	Cr	Mo	V	Ti	Al
0.4–0.8	0.8–1.4	1.5–2.5	4.0–5.0	84.0–89.3	4.0–6.3

The research material was chosen for good reason. There is hardly a modern structure, in which the most responsible tasks are not performed by titanium two-phase ($\alpha + \beta$) – alloys VT 22 and VT 23. High strength, low density, high specific strength, wide temperature range of application of these titanium alloys allows to significantly reduce the weight of structures and increase the reliability of their operation. High-strength titanium alloys VT 22 ($\sigma_{us} \geq 1150$ MPa, $\delta = 6-8\%$) and VT 23 ($\sigma_{us} \geq 1100$ MPa, $\delta = 10-15\%$) have a high level of strength and relatively high ductility. However, as shown by our previous studies [6, 7] performed on titanium alloy VT 22, impulse introduction of energy can significantly decrease the initial plastic deformation of the alloy with virtually no noticeable decrease in strength properties. With the optimal parameters of impulse introduction of energy, we managed to increase plastic deformation of alloy VT 22 followed by static stretching by 2.75 times compared to its initial state. Despite a much higher initial plastic deformation of alloy VT 23 as compared to alloy VT 22, which indicates a better production technology of this alloy, we could also expect some positive changes associated with an increase in plastic deformation of alloy VT 23 at the impulse introduction of energy. Two complex modes of loading were applied successively to a batch of 48 specimens from titanium alloy VT 23 under the following schemes:

1. Standard static stretching of the specimen to the stress level of $0.03\sigma_{ys}$ – pulse force uploading to the total stress level of $\sim \sigma_r$ ($\sigma_{\Sigma} = \sigma_{stat} + \sigma_{imp} \cong \sigma_{ys}$) – further static stretching to fracture of the specimen.
2. Standard static stretching of the specimen to the stress level of $0.03\sigma_{ys}$ – pulse force uploading to the total level of plastic deformation of $0.5...10.0\%$ – further static stretching to fracture of the specimen. In experiments on the DNP implementation, the fracture force of brittle samples was within the range of $42...156$ kN.

3. Results and discussion

The preliminary analysis of the experimental results showed that the maximum effect from impulse introduction of energy into alloy VT 23 occurs when the jumps of plastic strain attain values $\varepsilon_{imp} = 3.0...3.5\%$ in the process of the impulse introduction of energy into the alloy. In addition, at repeated static stretching, plastic deformation of the alloy increases by $30...35\%$. Fig. 2 presents some results of such experimental studies, where figures indicate the number of specimens tested.

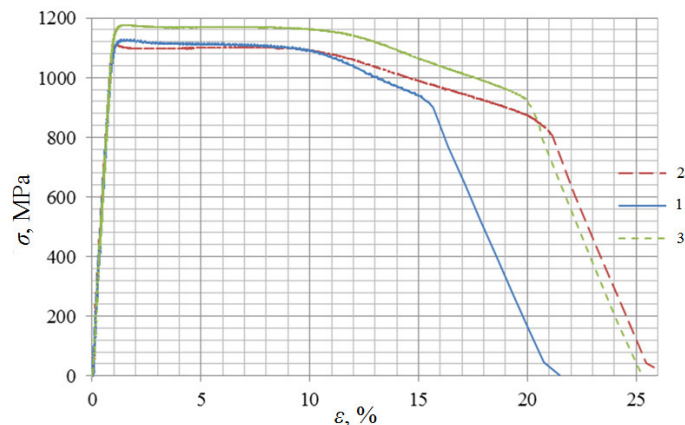


Fig. 2. Stress-strain curves of titanium alloy VT 23 at standard static stretching (curve 1) and at repeated static stretching after impulse introduction of energy (curves 2, 3).

As is seen in Fig. 2, impulse introduction of energy into alloy VT 23 really enhances plastic deformation of the alloy. Moreover, we can note that in some cases the strength properties of the alloy are also improved (see curve 2, 3 in Fig. 2). Detailed analysis of the metal-physical aspects of fracture of titanium alloy VT 23, taking into account impulse introduction of energy, is planned in the future. However, at this stage, we already obtained information on the analysis of fracture surfaces of titanium alloy VT 23 subjected to different modes of loading, which explains the effect of enhancing plastic deformation by impulse introduction of energy into alloy VT 23. Investigations were conducted on electron microscope “Scanning Elektron Microscope JEOL JSM-6610^{nx}”. The analysis of fracture

surfaces of specimens from alloy VT 23 tested under different modes of loading shows significant differences in their structure. Thus, fracture analysis of the specimen destroyed during static stretching (curve 1 in Fig. 2) indicates that the fracture in the central area of the specimen took place by the mechanism of separation, and in the near-surface areas by the mechanism of shear, with the formation of “microsteps” and local microtears of the material. With a slight magnification, fracture looks “smoother”, we can even state with a certain assumption that fracture of this type is characteristic of low-energy fracture. Microanalysis has revealed that the surface is formed by a plurality of quasi-facets with the size of 2–5 μm , whose boundaries look quite brittle, as evidenced by the lack of viscous borders of microdimples, Fig. 3.

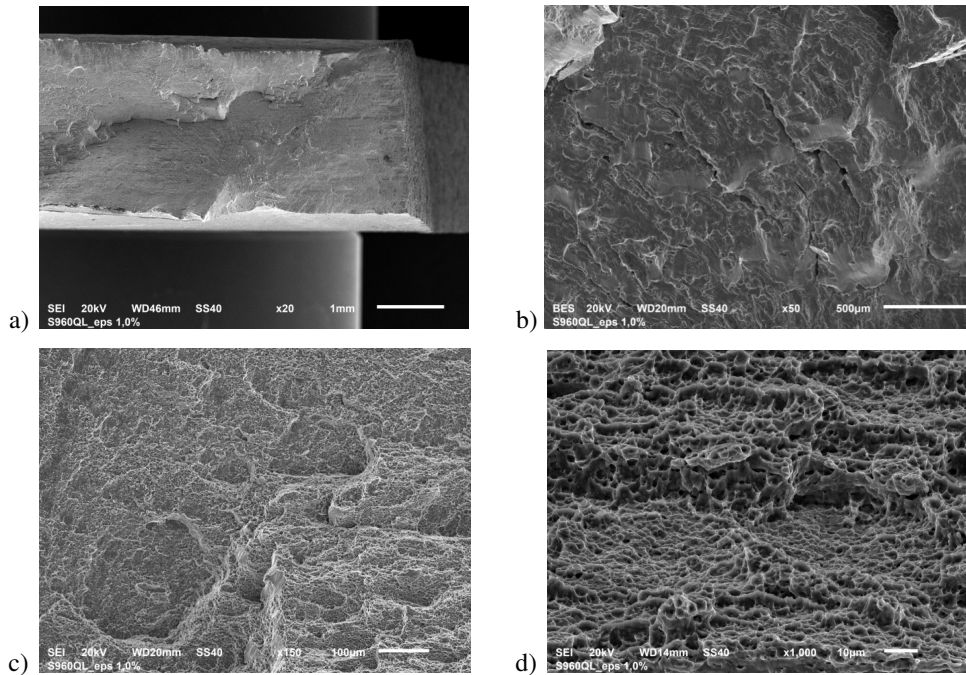


Fig. 3. Fracture pattern of specimen surface from alloy VT 23 at standard static stretching (curve 1 in Fig. 2).

Fig. 4 shows fracture patterns of the specimen surface from alloy VT 23 subjected to impulse introduction of energy (curve 2 in Fig. 2). As is seen, a fracture has significant distortions of its cross section, which shows a significant plastic deformation that occurred over one hour of deformation and fracture. It should be noted that the topography indicates the presence of deformation processes that occur by shear, separation and even rotation. In addition to the traditional micro-facet relief, longitudinal tears were found in the fracture, which, we believe, provide for the additional resistance of the material to fracture [8]. These tears are formed in the propagation of the crack in the direction transverse to the rolling direction of the sheet, from which specimens are made. The shape of micro-facets is close to circular, which allows us to consider them as microdimples with a flat bottom.

Fig. 5 shows fracture patterns of specimen surface from alloy VT 23 (specimen 3), which was also subjected to impulse introduction of energy. However, because of the stochastic nature of impulse introduction of energy into the alloy, as well as due to certain heterogeneity of the mechanical properties of the titanium alloy during its manufacture, in our case we can see some differences between fracture patterns and the previous specimen when rolling the sheet. In particular, at the microlevel, fracture pattern has a typical microdimple structure inherent to viscous fracture [7, 9].

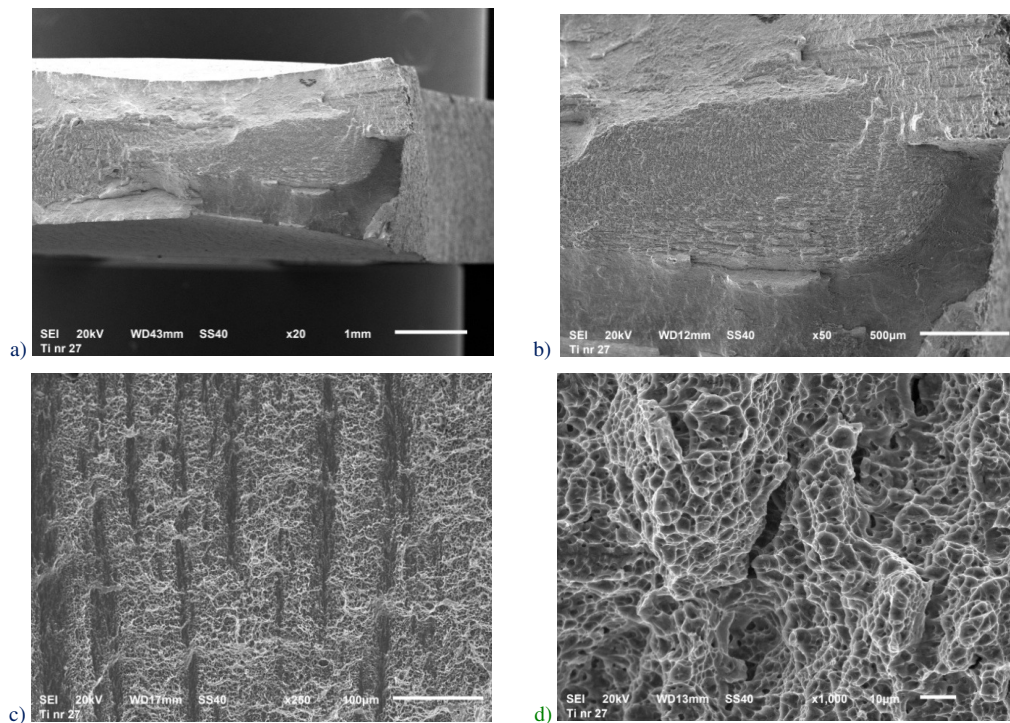


Fig. 4. Fracture pattern of specimen surface from alloy VT 23, subjected to impulse introduction of energy (curve 2 in Fig. 2).

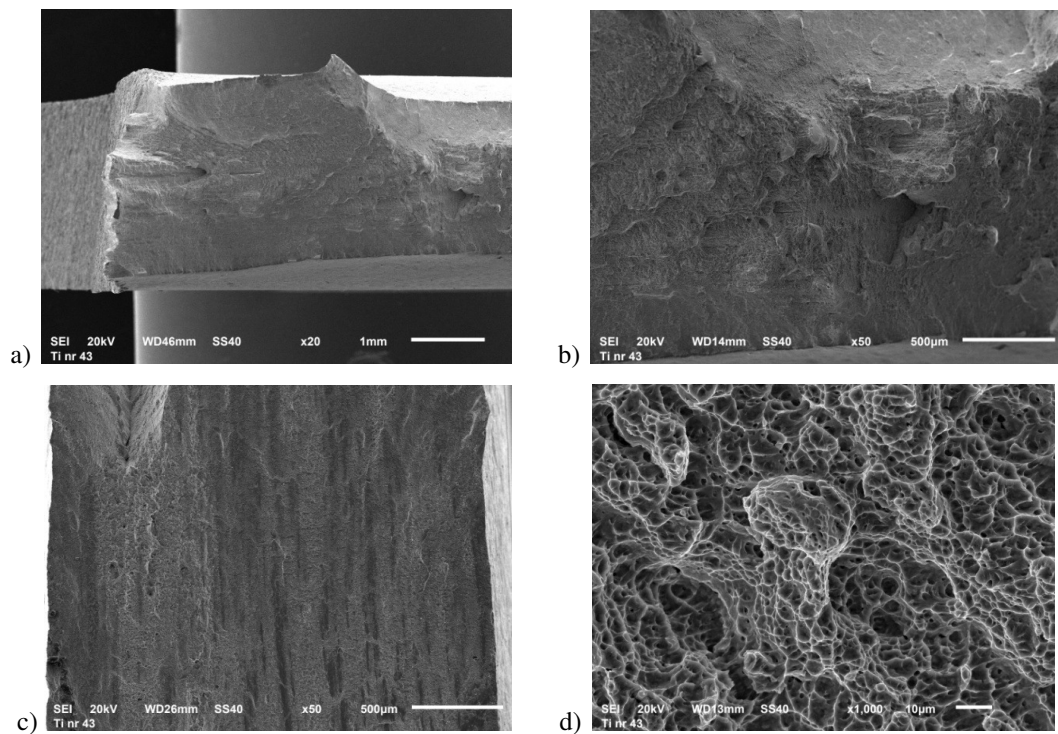


Fig. 5. Fracture patterns of specimen surface from alloy V T23 subjected to impulse introduction of energy (curve 3 in Fig. 2).

The surface is covered with dimples from 2 to 20 μm . Only individual quasi-facets are available, whose share is negligible. In general, the specimen topography is well-developed, which confirms its significant plastic properties. In addition, longitudinal tears are also found in the fracture, which provided for the additional resistance of the material to failure.

4. Conclusions

The impact of impact-oscillatory loading (DNP) with a frequency of 1...2 kHz on the variation of the mechanical properties of the sheet two-phase high-strength titanium alloy VT 23 under subsequent static stretching is investigated for the first time.

Investigations of the impulse introduction of energy into titanium alloy VT 23 have shown that when the jumps of plastic strain attain values $\varepsilon_{\text{imp}} = 3...3.5\%$ in the process of impulse introduction of energy into the alloy, plastic deformation of the alloy at repeated static stretching increases by 30...35%.

As a result, a greater emphasis on taking advantage of the improved processing capabilities of these alloys to minimize final aircraft component costs was placed. Based on fracture analysis of specimen surfaces from alloy VT 23, the effect of increasing plastic deformation under impulse introduction of energy into the alloy is explained.

References

- [1] N. G. Chausov, D. G. Voityuk, A. P. Pilipenko, A. M. Kuz'menko, Setup for testing materials with plotting complete stress–strain diagrams, *Strength Mater* 36 (2004) 532–537.
- [2] N. G. Chausov, A. P. Pilipenko, Influence of dynamic overloading on fracture kinetics of metals at the final stages of deformation, *Mechanika* 48 (2004) 13–18.
- [3] M. G. Chausov, V. B. Berezin, A. P. Pylypenko, V. B. Hutsaylyuk, Strain field evolution on the surface of aluminum sheet alloys exposed to specific impact with oscillation loading, *J. Strain Anal. Eng. Des.* 50 (2015) 61–72.
- [4] N. G. Chausov, E. E. Zashimchuk, L. I. Mackashova et al., Peculiarities of plastic materials deformation during dynamical nonequilibrium processes, *Fact. Lab. Mater. Diagn.* 75 (2009) 52–59.
- [5] E. E. Zashimchuk, L. I. Mackashova, T. V. Tutchak, N. G. Chausov et al., Peculiarities of structural transformation in plastic materials under abrupt changes in loading conditions, *Phys. Mesom.* 12 (2009) 175–179.
- [6] M. G. Chausov, A. P. Pylypenko, V. B. Berezin, L. I. Markashova, O. S. Kushnariova, V. B. Hutsaylyuk, Influence of impact-oscillatory loading upon the mechanical properties of the VT-22 titanium alloy sheet, *J. of Mater. Eng. and Perform.* 25 (2016) 3482–3492.
- [7] M. Chausov, P. Maruschak, A. Pylypenko, L. Markashova, Enhancing plasticity of high-strength titanium alloys VT 22 under impact-oscillatory loading, *Philosophical Magazine*, 97 (2017) 389–399.
- [8] P. O. Maruschak, R. T. Bishchak, D. Ya. Baran, Dispersed and localized damages of heat-resistant steels, Ternopil, “Libra Terra”. 2016. 228 p. (in Ukrainian)
- [9] P. Maruschak, A. Menou, M. Chausov, V. Mocharskyi, Fractographic analysis of surface and failure mechanisms of nanotitanium after laser shock-wave treatment, *Key Engineering Materials* 592–593 (2014) 346–349.