STUDY OF THE INFLUENCE OF ACOUSTIC FIELDS ON THE MECHANICAL AND TECHNOLOGICAL PROPERTIES OF TITANIUM VT1-0

© 2025 E. Y. Remshev*, G. A. Vorob'eva, A. I. Olekhver, T. M. Abu Fadda

BSTU "VOENMEH" named after D.F. Ustinov, St. Petersburg, Russia

e-mail: remshev@mail.ru

Received March 27, 2024

Revised November 06, 2024

Accepted November 17, 2024

Abstract. The effect of aeroacoustic treatment (AAT) on the mechanical and technological properties of titanium VT1-0 is investigated. The dependence of the strength and ductility characteristics on the type of preliminary titanium treatments has been established: annealing, AAT and only AAT before plastic deformation significantly reduce the value of σB and increase plasticity, which reduces deformation forces, increases the deformation rate, and shortens the processing time.The effect of pre-treatment on the process of plastic deformation of VT1-0 (a decrease in strength by ~ 200 MPa) is similar in terms of the effect of the electroplastic effect (EPE) on the strength of the wire from VT1-0.

Keywords: *titanium VT1-0, heat treatment, aeroacoustic treatment, plastic deformation, electroplastic effect*

DOI: 10.31857/S00153230250112e9

INTRODUCTION

Studies of the influence of magnetic fields, ultrasound (US) and electric current on the physical, mechanical and technological properties of crystalline bodies [1–11] have established that processing using physical fields allows the creation of materials with new, higher properties [1, 5, 9] and with the possibility of manufacturing products using methods using high deformation rates at low stresses and temperatures. Softening (plastic effect - PE) when mechanical vibrations (US) are applied to a quasi-static mechanical load of samples is the acoustoplastic effect - APE [6, 7]; softening under the influence of electric current, which is passed during plastic deformation of samples - electroplastic - EPE [8–11] and under the action of a constant magnetic field - magnetoplastic - MPE [2–4] effects. The influence of physical fields on the properties of materials is often used in the modernization of existing technological processes and the creation of new technologies. To obtain products with specified physical, operational properties and structure of the material, it is necessary to study the processes occurring in materials that have not previously been subjected to these types of processing, since automatic reproducibility of the results of the impact of physical fields on the properties of different materials is practically not observed. This also applies to the effect of aerothermoacoustic (ATAO) and aeroacoustic (AAO) processing, implemented in the frequency range of 600–2000 Hz, on the structure of steels and alloys in order to form the required complex of their mechanical and technological properties [12–16]. In this work, the effect of aeroacoustic processing on the mechanical and technological properties of titanium VT1-0, which is a widely used corrosion-resistant material, was investigated.

MATERIAL, PROCESSING TECHNOLOGIES AND RESEARCH METHODS

The study of the AAT effect on titanium properties was conducted on VT1-0 rods; the rods are welded. The mechanical properties of the rods in the initial state (Table 1, mode 1/1) were within the limits: σ_B=355–540 MPa; δ=19–20%; ψ=38–50%, as determined by GOST 26492-85 for VT1-0 rods. Welding did not cause a significant change in mechanical properties. However, welding increases the level of residual stresses, for the reduction of which annealing is provided in the scheme of technological processes that include welding. Some samples before AAT were subjected to annealing (650 °C for 2 hours).

The parameters of aeroacoustic treatment during AAT include: temperature, cooling rate, gas flow rate, amplitude-frequency characteristics, which are regulated by varying the geometric characteristics of the installation, and the time of thermo-acoustic exposure. The working gas can be air, nitrogen, and other media. During AAT, the impact of temperature and acoustic fields (ATAE) can be carried out in order to form material properties in the required direction or only acoustic fields and gas flow – AAT. AAT can be used as a strengthening treatment, as well as a treatment that reduces residual stresses obtained during previous processing in the product material, and increases plasticity, which is determined by the parameters of the processing modes [12–16]. As a strengthening treatment, AAT is a complex process that includes preliminary treatment, which can be cold plastic deformation or heat treatment with cooling in traditional media (water, oil, air) or in a powerful acoustic field of the sound frequency range, with simultaneous exposure to gas flow in the speed range from tens to hundreds of meters per second. At the same time, the material is cooled to negative temperatures in the expanding gas flow, i.e., additional cold treatment is implemented [15, 16]. One of the main operations in ATAE technology is the processing of parts, including cryogenic exposure, in a powerful acoustic field of the sound range of discrete frequencies (600–1200 Hz) with a sound pressure level up to 150–160 dB in a gas flow in the resonator of a gas-jet sound generator (GSG).

Samples in the initial state were subjected to aeroacoustic treatment for 10 minutes at 20°C, without preliminary heating, using special technological equipment including a GGZ. A container with samples in the initial state and after annealing was placed in the GGZ resonator. The samples were processed in the GGZ resonator according to the following modes: AAT ^{1} and AAT ^{2}, which differ in amplitude-frequency characteristics.

Mechanical properties were determined by testing five-fold cylindrical samples for static tension according to GOST 1497-84 on a Shimadzu AGX-100kN machine. The error in determining the load during testing does not exceed 1%, and the stress (σ_u, $\sigma_{0.2}$) - 5 MPa. During the testing of samples, "load-deformation" diagrams were synchronously recorded and the time of material deformation was fixed. This made it possible to determine the strain rate (change in relative elongation (%) per unit time; its dimension is %/s).

RESEARCH RESULTS AND DISCUSSION

The results of mechanical tests for static tension of VT1-0 samples in the initial state, after annealing, annealing and processing according to AAT ^{1} and AAT ^{2} modes are given in Table 1.

Table 1. Mechanical properties of titanium VT 1-0 samples (welded) in the initial state, after annealing and aeroacoustic treatment

Mode No./ Sample No.	Type of treatment	$\sigma_{0.2}$, MPa	σ_B, MPa	δ, %	ψ, %

1/1	Initial state	337	408	29	63
1/2	Initial state	340	418	33	65
2/3	Annealing	309	398	34	63
2/4	Annealing	331	411	31	63
3/5	Annealing + AAT [1]	310	398	35	64
4/6	Annealing + AAT [2]	172	251	34	63
4/7 *	Annealing + AAT [2]	55	119	37 *	65
4/		114	185	35	64
5/8	AAT [2]	199	282	36	64
5/9 *	AAT [2]	62	104	28 *	60
5/10	AAT [2]	75	166	33	64
5/		102	184	31	63

* Samples were not destroyed during the testing process. When the sample number is missing, the average values of four tests are provided

Rupture of all samples occurred outside the welding zone of the rods, which allows excluding welding as a factor that significantly affects the properties of the material. Two samples (No. 7, 9) did not break during the testing process, as the load level reached a value that was below the sensitivity level of the equipment determining the moment of sample destruction.

Annealing and treatment according to mode No. 3 with AAO [1] do not significantly change the strength of titanium, slightly increasing its ductility compared to the characteristics in the initial state. Both strength characteristics $\sigma_{0.2}$ and σ_B decrease if AAO [2] (mode No. 4) is carried out after annealing, with the level of yield strength - $\sigma_{0.2}$ decreasing more significantly, while ductility increases. One of the samples treated according to mode 4 (4/7) did not break during the tensile test (values of σ_B = 104-120 MPa below the sensitivity level of the machine). Treatment according to mode No. 5 with AAO [2], without preliminary annealing, has an effect on the strength of VT1-0 similar to treatment according to mode No. 4; the average level of σ_B = 184 MPa, ductility is somewhat less than with preliminary annealing δ=31%. During testing, sample No. 5/9 also did not break due to low values of σ_B. The relative elongation (δ) of unbroken samples was determined by the value equal to ΔL at the moment of stress reduction to "0". Stress-strain diagrams of titanium samples after the treatments indicated above are presented in Fig. 1.

Fig. 1. Stress-strain diagrams of VT1-0 titanium samples: a - annealing; b, c - annealing, AAO [2]; d, e - AAO [2] without annealing. Samples in Fig. 1c and e did not break.

In the annealed state (Fig. 1a, sample No. 2/4) at stresses above 400 MPa, deformation from 9 to 24% occurs with a slightly changing load (~10-15 MPa), this type of stress-strain diagram is characteristic of other samples that have undergone different types of treatment. With treatment according to mode No. 3/5 (AAO [1] after annealing), the form of the diagram is practically similar to that shown in Fig. 1a, as well as the value of the maximum stress (σ_B). AAO [2] with preliminary annealing - sample No. 4/6 (Fig. 1b) significantly reduces the level of maximum stress during deformation.

After similar treatment - sample No. 4/7 (Fig. 1c), the maximum stress decreases to 120 MPa, while the sample did not fail during testing. In the strain range from 12% to 28% of this sample, a small, step-like increase in load indicates deformation by twinning. AAO [2] treatment without preliminary annealing (Fig. 1d, sample No. 5/10) also reduces the maximum stress; sample No. 5/9

(Fig. 1e) did not fail during testing for the reason mentioned above; plasticity under this treatment mode is lower than under the treatment mode in which AAO ^{2} is preceded by annealing.

The strain rate of titanium during testing was determined in the plastic deformation region: V_1 - from values $\sigma_{0.2}$ - until reaching the conventional stress σ_B (area of cross slip of dislocations) and V_2 - from the level of values σ_B (from the moment of neck formation in the sample) until fracture or load reduction to "0". The magnitude of titanium deformation was determined in zones: Δ_1 - with changes in maximum load not exceeding 10 MPa; Δ_2 - at approximately constant load, the results are shown in Table 2.

Compared to the initial state after annealing, the strain rate increases, most intensively in the region until reaching stresses σ_B - V_1, while maintaining the values of other parameters. AAO ^{1} after annealing (mode No. 3) slightly increases the deformation of the material - Δ_2 at constant load.

Table 2. Influence of processing mode of titanium VT1-0 on strain rate and tensile diagram parameters

Mode No./ Sample No.	Type of processing	σ_B, MPa	V_1^*, %/s	V_2, %/s	Δ_1^{**},%	Δ_2,%	σ_P, MPa
1	Initial state	413	0.41	0.48	15	6	280
2	Annealing	405	0.52	0.52	15	7	274
3	Annealing+ AAO ^{1}	398	0.51	0.52	15	10	272
4/6	Annealing+ AAO ^{2}	251	0.53	0.54	16	8	120
4/7	Annealing+ AAO ^{2}	119	1.0	0.5	18	8	–
5/1	Initial state+ AAO ^{2}	283	0.53	0.52	20	7	160
5/2	Initial state+AAO ^{2}	104	0.53	0.52	17	5	–
5/3	Initial state+AAO ^{2}	166	0.52	0.52	21	7	40

* V_1, V_2 %/s – strain rates of titanium specimen corresponding to sections of the tensile diagram: 1 – from $\sigma_{0,2}$ to reaching σ_B; 2 – from σ_B to fracture or load reduction to "0".

** Δ_1, Δ_2, % – relative deformation of titanium: Δ_1 – in the zone of maximum load change not exceeding 10MPa; Δ_2 – at constant load. Samples 4/7 and 5/2 did not break. In the absence of a sample number, the average values of four tests are given.

A more significant effect on the properties of VT1-0 is exerted by AAT ^{2} (modes No. 4, 5), implemented both after annealing and in its absence; along with a significant decrease in σ_B and $\sigma_{0.2}$ the deformation rate V_1 and the deformation value Δ_1 increase, and with preliminary annealing, the values of V_2 and Δ_2 increase. The amount of deformation under constant load increases with both types of AAT. The stress at which the sample ruptures – σ_P, decreases when titanium is processed according to modes No. 4, 5.

The increase in deformation rate and decrease in deformation force after AAT leads not only to reduced energy consumption but also increases equipment service life, including improving wear resistance of equipment parts.

In work [8], the electro-plastic effect was investigated during the stretching of a 0.8 mm diameter wire made of VT1-0 titanium. The greatest strength reduction from the EPE impact for VT1-0 titanium wire was in its annealed state and reached ~200 MPa.

The effect of aeroacoustic treatment (reduction of tensile strength from ~410 MPa (initial state) to average values of ~185 MPa (treatment according to mode No. 5)) is similar in effectiveness to the influence of EPE. Consequently, this allows considering aeroacoustic treatment as a technology for affecting VT1-0 titanium, after which an acousto-plastic effect (APE) is observed during the plastic deformation process.

In metals with high stacking fault energy, which includes titanium, flat dislocation pile-ups are formed during deformation. At the stage of multiple slip, barriers are formed as a result of the intersection of dislocations from different systems, and dislocations are slowed down at these barriers. With high stacking fault energy, cross slip occurs easily. Dislocation pile-ups will bypass barriers and again interact with dislocations of other systems and form new barriers.

During the AAT, multi-cycle complex impact on the metal of a non-stationary gas flow and discrete acoustic fields with a frequency of 0.4-2.0 kHz was carried out, under the influence of which, presumably, dislocation detachment from barriers occurs, dislocation mobility increases, determining the decrease in strength, increase in plasticity, and reduction of internal stresses [12-16].

The authors previously investigated the effect of AAT on the magnitude of residual stresses (RS) in the VT23 alloy. The maximum level of tensile RS on the surface in the initial state reached 400 MPa, decreasing to 300 MPa at a depth of 700 μm, and then remained unchanged. After ATAO, the RS value in the alloy decreased to 230 MPa on the surface. Annealing reduces the RS on the surface of VT1-0 titanium from 1035 MPa to 942 MPa. Therefore, it can be assumed that AAT also reduces the RS value in VT1-0 titanium.

CONCLUSION

Aeroacoustic treatment (AAT) of VT1-0 titanium has a significant effect on its mechanical and technological properties. After AAT, the relative elongation increases, while the ultimate tensile strength and yield strength decrease. This reduces deformation forces, increases the deformation rate , i.e., an acoustoplastic effect is observed. The effectiveness of APE is similar to the electroplastic effect (EPE) for VT1-0 wire. Annealing before AAT [2] additionally increases the plasticity of titanium. The advantage of AAT is that the treatment is carried out before plastic deformation, at 20°C and, therefore, does not require the development of a special installation for alloy deformation, which is necessary to achieve EPE during metal deformation.

In addition, increasing the deformation rate and reducing the deformation force leads not only to reduced energy costs but also improves equipment durability, including increasing the wear resistance of die parts.

FUNDING.

The research was carried out with the support of the Russian Science Foundation grant No. 24-29-00338, (https://rscf.ru/project/24-29-00338/).

CONFLICT OF INTERESTS

The authors of this work declare that they have no conflict of interest.

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