Efficiency of electromechanical treatment of VT22 Titanium Alloy in the manufacture and repair of transport components

S Yakovlev¹, J Nuretdinova² and A Mishanin³
¹Ulyanovsk State Agrarian University named after P.A. Stolypin, Ulyanovsk, Russian Federation
²Ulyanovsk State University, Ulyanovsk, Russian Federation
³Samara State Agrarian University, Samara, Russian Federation
E-mail: ⁴Jakseal@mail.ru

Abstract. The high efficiency of VT22 titanium alloy hardening by electromechanical treatment in the manufacture and repair of transport components is determined. The experiments on determining the heat resistance of VT22 titanium alloy structures hardened by electromechanical treatment showed that their maximum operating temperature is limited to 550 °C. When transport operating in environments with higher temperatures, recrystallization processes begin in hardened areas.

1. Introduction

Food security of the country is directly related to the development of modern technological processes for the manufacture and repair of machine parts. Among these technologies is Electromechanical Treatment. Distinctive features of Electromechanical Treatment are: instantaneous local heating of the contact point between the tool and the component due to current and frictional effect, accompanied by significant pressure on the processed material [1]; short-term thermomechanical effects are measured in centiseconds; high cooling rate due to intensive heat transfer into the component [2]; no need for the use of protective environments, vacuum and special consumables; no oxidation, decarburization, hydrogenation; the ability to process parts of any size and configuration; the ability to change modes and processing schemes, as well as to change tools flexibly and quickly; low costs for the manufacture and operation of technological equipment; installability of electromechanical treatment processes in a typical cycle of manufacturing or repair of machine parts, etc.

Electromechanical treatment is successfully used for steel and cast iron processing [1, 2], as well as for copper alloys processing [3]. Electromechanical treatment technologies are effective in the manufacture and repair of shafts and holes, operative parts of agricultural machinery, splined couplings, key and threaded connections.

The purpose of the work is to study the efficiency of electromechanical treatment of VT22 titanium alloy.

2. Results and Discussion

VT22 alloy (State Standard GOST 19807-91) refers to two-phase thermally hardened (α+β)-alloys and has the best combination of technological and mechanical properties due to alloying of titanium with aluminum and β-stabilizers. According to the structure obtained as result of quenching, VT22 belongs to the transition class. The presence of a large amount of β-phase (up to 50%) provides the alloy with
the highest strength and hardness among (α+β)-alloys both in the annealed and hardened state. The presence of aluminum (4.4...5.7%) in the VT22 alloy increases the thermal stability of the β-phase [4].

VT22 alloys are hardened by heat treatment through quenching and aging. Quenching consists in heating to the β-field with cooling in water. The disadvantages of this technology is the possibility of significant warping of components, oxidation and hydrogenation of the surface layer of products. Moreover, the source of hydrogen and oxygen is water. At high temperatures, the reaction between titanium and water Ti+2H₂O→ TiO₂+4H⁺+4e⁻ takes place, resulting in the formation of titanium oxide and a solid solution of hydrogen in Ti, which causes hydrogen embrittlement [4]. If the cooling rate is insufficient during quenching, a metastable intermediate α'-phase may appear in the structures of the quenched alloy, which also embrittles the alloy.

During the electromechanical treatment of VT22 titanium alloy, depending on the technological modes (current I, machining speed v and retaining force on the tool at the workpiece surface F), the surface hardening to 4800 MPa (47 HRC) is ensured with an initial hardness of 3028 MPa (33 HRC). The hardening depth t, depending on the type of hardening, reaches 3 mm. So, in electromechanical smoothing the maximum hardness was 4190 MPa (42 HRC), with a maximum hardening depth of t_max = 0.2 mm; in electromechanical hardening - 4800 MPa (47 HRC) with t_max = 0.4 mm; with electromechanical surface quenching - 4600 MPa (46 HRC) with t_max = 1.8...3 mm. As a result of the electromechanical treatment of the VT22 alloy by the above methods (electromechanical smoothing, electromechanical hardening, electromechanical surface quenching), surface hardening is observed, which is the structure of a white layer — martensite (α′+β′-structure) [8]. The different magnitude and depth of hardening is explained by the different intensities of the electromechanical (thermomechanical) impact on the surface layer of the processed material.

To determine the heat resistance of the VT22 titanium alloy structures (white layer) hardened by electromechanical treatment, samples were treated with electromechanical surface quenching on a screw-cutting lathe with the following mode: current I=1400 A, retaining force on the tool at the workpiece surface F=150H, machining speed v=1 m/min. BrKh1 bronze rollers (radius r_t=30 mm; strip width in working section b=3.5mm) were used as the tools in electromechanical surface quenching.

Samples of hardened structures were heated in a muffle furnace at temperatures of 100, 200, 300, 400, 500, 600, 700 °C for 3 hours. The temperature in the furnace was monitored using a thermocouple of the multimeter Mastech MY62. After three hours of heating, the samples were mounted in steel rings and poured with protacrylic resin, then subjected to trimming, grinding and polishing. Two reagents were used for etching:

1) 2% nitric acid, 2.5% fluoric acid, 95.5% water;
2) 20% nitric acid, 20% fluoric acid and 60% glycerin [7].

The microhardness of the hardened layer was measured by the Vickers method (State Standard GOST R ISO 6507-1–2007) with a 100 g load [6] by means of a PMT-3 instrument. The result was converted to Pa and HRC.

As result of studies, it was found that three-hour heating of samples at a temperature of 600 °C leads to the elimination of hardened areas (white layers). Changes in the structure and properties of areas hardened by electromechanical treatment occur in the temperature range from 500 to 600 °C.

To determine the onset of decomposition of hardened structures, additional experiments were carried out at temperatures of 525, 550, and 575 °C.

Figure 1 shows the dependence of microhardness of structures hardened by electromechanical surface quenching (within 3 hours) on the heating temperature. Hardness measurements were carried out for areas treated with electromechanical surface quenching at a depth of 1 mm.
The figure shows that a sharp decrease in hardness begins at heating temperatures above 550 °C. When heated to a temperature of 575 °C, the hardness decreases to 4000 MPa. Therefore, the recrystallization processes of structures hardened by electromechanical treatment begin when they are heated above 550 °C.

The graph also shows that at temperatures close to 300 °C there is a slight decrease in hardness to 4460 MPa. This is explained by the fact that at temperatures of 300...350 °C, when heating alloys with a hardened β′-structure, a ω-phase is formed, which slightly reduces hardness [4].

Thus, the analysis of methods for hardening the titanium alloy VT22 showed that electromechanical treatment can effectively harden the surface layers of parts requiring high strength ratio. The experiments on determining the heat resistance of VT22 titanium alloy structures hardened by electromechanical treatment showed that their maximum operating temperature is limited to 550 °C. When operating in environments with higher temperatures, recrystallization processes begin in hardened areas.

3. Conclusion
Electromechanical treatment processes can be recommended as an effective hardening treatment of transport parts made of VT22 titanium alloy operating at elevated temperatures.

References
[1] Askinazi B M 1989 Reinforcing and Reparation of Machine Parts by Electromechanical Processing Mashinostroenie (Moscow)
[2] Yakovlev S A 2014 Influence of Electrophysical Parameters on Electromechanical Processing of Machine Parts (Monograph, Ulyanovsk: Ul’yanovsk. Inst. Grazhd. Aviats)
[3] Morozov A, Fedotov G, Kundrotas K 2020 The influence of volumetric electromechanical mandreling on the lead yield from the matrix material on the bronze bearing bushing surface IOP Conference Series: Materials Science and Engineering 709, 3
[4] Arzamasov B M, Makarova V I, Mukhin G G et al 2004 Material Science: Manual for Higher Education Institutions (Moscow: Moős. Gos. Tekh. Univ. im. N.E. Baumana)
[5] Yakovlev S A, Zamal’dinov M M, Nuretdinova Y V, Mishanin A L, Igonin V N, Sotnikov M V, Khabarova V V 2018 Electromechanical hardening of VT22 titanium alloy in screw-cutting lathes Russian Engineering Research, 38, 6
[6] GOST (State Standard) R ISO 6507-1-2007 2008 Metals and Alloys. Vickers Hardness Test Part 1 Test Method (Moscow: Standartinform)
[7] Beckert M and Klemm H 1985 Handbuch der metallographischen Ätzverfahren (Leipzig VEB Deutscher Verlag für Grundstoffindustrie)