Hydrogenous Phase Concentration: Impact On The Structural Condition And Fracture Mechanics Of Technically Pure Titanium After Different Conditions Of Hydrogenation

O. T. Cherney, V.A. Zotova, A.A. Permovsky, Z. V. Smirnova, O.I. Vaganova

Abstract*: The high rate of mechanical strength places technically pure titanium on a par with high-tension steel and is a strong reason for using this material in various branches of industry and medicine. However, when the material is being processed, a number of difficulties arise related to the chemical activity of titanium. That's why the study of the impact on structural condition and fracture mechanics of technically pure titanium after different conditions of hydrogenation was carried out. Technical titanium VT1-0 as received was selected as a material for the experiment. Flat samples with operation part dimension 18×5×2 mm were produced for tensile test, surface texture analysis, and X-ray crystal analysis.As a result of the experiment, data of changes of macrostresses, microstresses, sizes of blocks of mosaic and concentrations of titanium hydride against the limit solubility of hydride phase in titanium at the surface of metal depending on the duration of cathode electronic degreasing were obtained. It was noted that there are hydride seeds in the surface layer of the metal at the initial stages of hydrogenation and their growth and separation in an individual phase is possible at later stages.

Key words: fracture mechanics, hydrogenation, titanium hydride concentrations.

I. INTRODUCTION

Technically pure titanium is widely used in different branches of industry, particularly, aircraft engineering, chemical industry, radio engineering [4], [6], [14], as well as medicine. [7], [16]

Titanium applicability is explained by both mechanical (strength, plasticity) and physical properties (specific weight, coefficient of thermal expansion, temperature conductivity coefficient, stainless property, etc.) [1], [11], [13]. However, there are some difficulties in production when producing titanium components and they're primarily related to its chemical activity with gases (hydrogen, nitrogen, oxygen and in some cases with carbon) [5], [9], [12], [15]. Titanium most actively interreacts with oxygen, resulting in so-called hydride fragility caused by a significant distortion of the crystal lattice and low bonding of titanium and titanium hydride phase seeds [8], [3]. This creates favourable conditions for the movement of the crack along the border lines of these phases, even at a low level of metal stress state, and destruction of the component (Fig. 1).

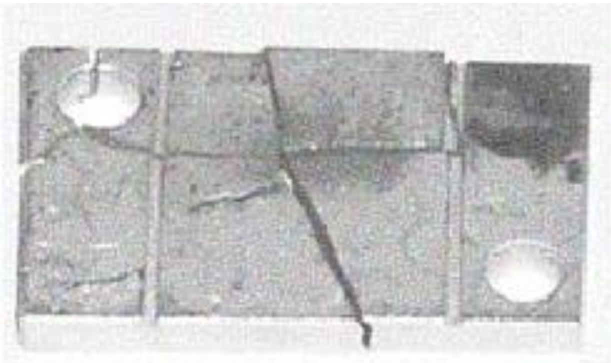

Fig. 1 - Component destruction due to oxygen impact

Titanium is saturated with hydrogen when it interreacts with corrosive media (acids, lyes, solutions), as a result, metal embrittlement may occur [10]. Under production conditions, the maximal impact of corrosive media on titanium components takes place during galvanic treatment. That's why studying the impact of the processes of galvanic treatment on the structural parameters and failure mechanics of titanium is of scientific and productive interest.

II. STUDY METHODOLOGY

Technical titanium VT1-0 as received was selected as a material for the experiment. Flat samples with operation part dimension 18×5×2 mm were produced for tensile test, surface texture analysis, and X-ray crystal analysis in order to implement the experiment.

Sample preparation was carried out under two modes according to GOST:

1.cathode electronic degreasing, for a duration of 0, 10, 20, 30, 40 and 60 minutes, etching, defectation;

2.cathode electronic degreasing, for a duration of 0, 10, 20, 30, 40 and 60 minutes, etching, defectation, hydride treatment, nickel coating.

X-ray crystal analysis of the samples was carried out using DRON 2. Tensile tests were carried out using INSTRON. Preloading was carried at a rate of 1 mm/min. The development of deformation relief was studied at the front surface of flat samples using optical microscope Zeiss Axiovert 25 with an increase x500.

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III. EXPERIMENTAL DATA

A. X-ray crystal analysis.

As a result of X-ray crystal analysis, data of changes of macrostresses, microstresses, sizes of blocks of mosaic and concentrations of titanium hydride against the limit solubility of hydride phase in titanium at the surface of the metal depending on the duration of cathode electronic degreasing are represented
in Table 1.

Table 1 X-ray crystal analysis results

State	Macrostresses, hPa	Microstresses, $\Delta\alpha/\alpha\times10^{-2}$	Block size L, (μm)	Content TiH_2, %
Hydrogenation 10 min	+0,96 ±10%	0.186 ±0,1%	0,377 ±0,1%	48 ±10%
Hydrogenation 20 min	+0,49 ±10%	0.675 ±0,1%	0,715 ±0,1%	69 ±10%
Hydrogenation 30 min	+0,67 ±10%	0.605 ±0,1%	0,605 ±0,1%	69 ±10%
Hydrogenation 40 min	+0,67 ±10%	0.812 ±0,1%	0,539 ±0,1%	75 ±10%

Findings indicate that with an increase in the duration of cathode electronic degreasing the content of titanium hydride in the surface layer of the main metal increases. Meanwhile, there's a sharp increase in the level of macrostresses at the initial stage of degreasing. The reaching of macrostresses of the level of 0,96 hPa can be caused not only by the introduction of hydrogen in the surface layers of titanium, crystal lattice distortion and hydride phase formation but also, supposedly, the impact of previously applied protective galvanic coating. Nickel coating increases the strength properties of components in general. The increase of the hydride phase in metal increases the level of microstresses, which is achieved by titanium crystal lattice distortion and processes related to titanium conversion to chemical compound TiH2. The fluctuation of microstresses level can be explained as follows. It's known that titanium hydride is characterized by a low bonding with the metal. It's also known that in the process of hydrogenation the level of titanium roughness increases [2]. It follows from the above that the fluctuation of titanium hydride concentration is caused by the breaking of interatomic bonds and its splitting off the metal surface and, at the same time, continuous saturation of titanium with hydrogen. The breaking of interatomic bonds of titanium and titanium hydride leads to a decrease in the level of microstresses. However, a significant decrease is not achieved due to the continuous formation of a new hydride compound in titanium. While increasing the level of microstresses, the size of blocks of mosaic increases too, which is attributable to the formation and growth of hydride phase seeds.

The curve of change of titanium hydride concentration at the metal surface depending on the duration of hydride treatment is represented in Fig. 2.

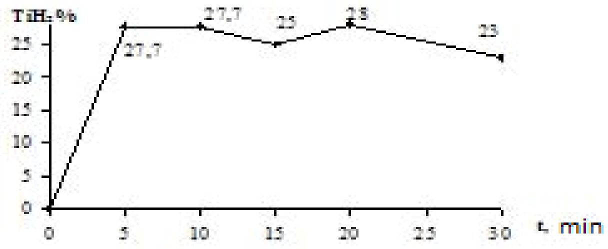


Fig. 2 – Impact of the duration of titanium VT1-0 hydrogenation on the level of saturation of surface with titanium hydride

It follows from the curve that TiH_2 concentration is also of a fluctuating nature. An increase in the duration of hydrogenation gives rise to an increase in the nonhomogeneity of surface composition, as evidenced by the change of the degree of resolution of the doublet line of titanium (Θ =22°) and TiH2 line (Θ=22,25°) in X-ray patterns obtained as a result of the study (Fig. 3).

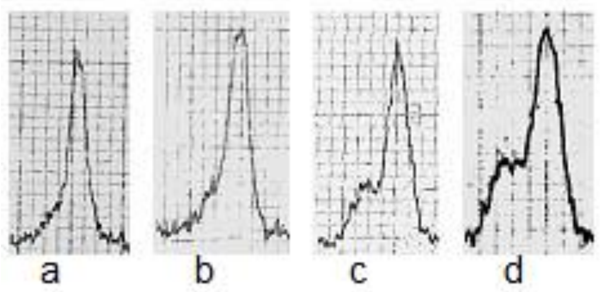


Fig. 3 – Resolution of doublet line of titanium sample at hydrogenation within:
a – 0 min, b –10 min, c –20 min, d –30 min

B. Stress-strain curves.

Uniaxial tensile test of samples exposed to both hydrogenation (Fig. 4) and hydrogenation with the following galvanic coating with nickel (Fig. 5) showed that hydrogenation of the thin surface layer and the presence of galvanic coating have virtually no impact on the mechanical properties of the metal (Fig. 4, 5).

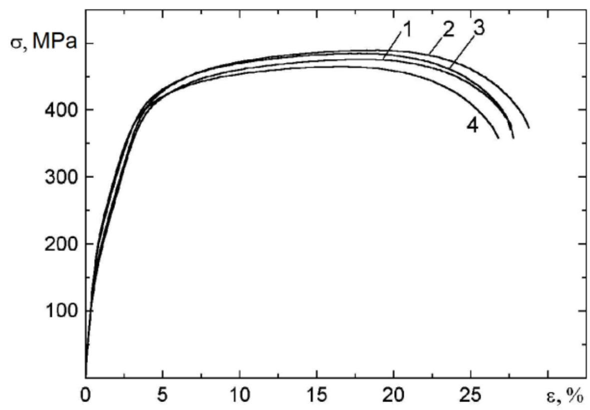


Fig. 4 Tensile diagram of samples hydrogen-charged within: 1 – 0 min, 2 –10 min, 3 –30 min, 4 –60 min

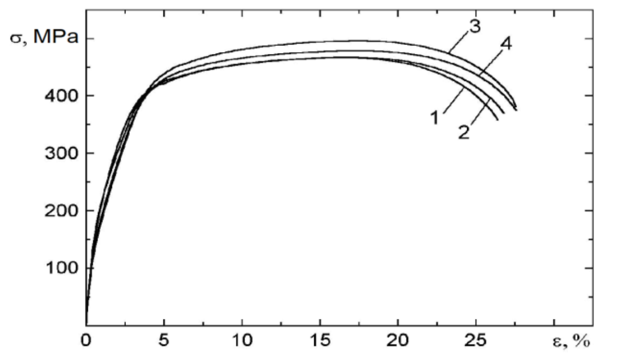
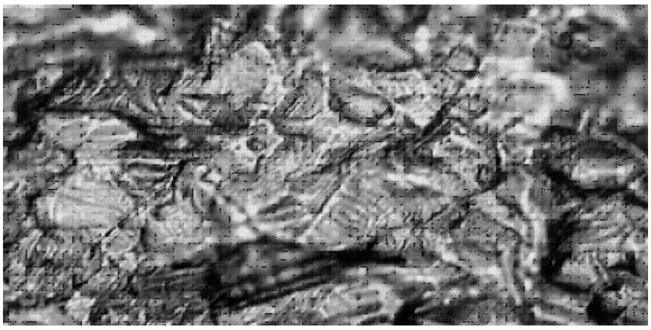


Fig. 5 Tensile diagram of samples hydrogen-charged within: 1 – 0 min, 2 – 10 min, 3 – 30 min, 4 – 60 min and nickel coated

C. Development of deformation relief.

In the course of the analysis, the comparative evaluation of structure change with an increase in the level of hydrogenation in the area of destruction (samples' neck), neck initiation and the zone of small plastic strains was carried out. To carry out the analysis from nickel coated samples, the galvanic layer was mechanically peeled off. The photographs of the development of deformation relief are represented in Fig. 6 – 8.

Fig. 6 – Relief external view in the area of initiation of neck

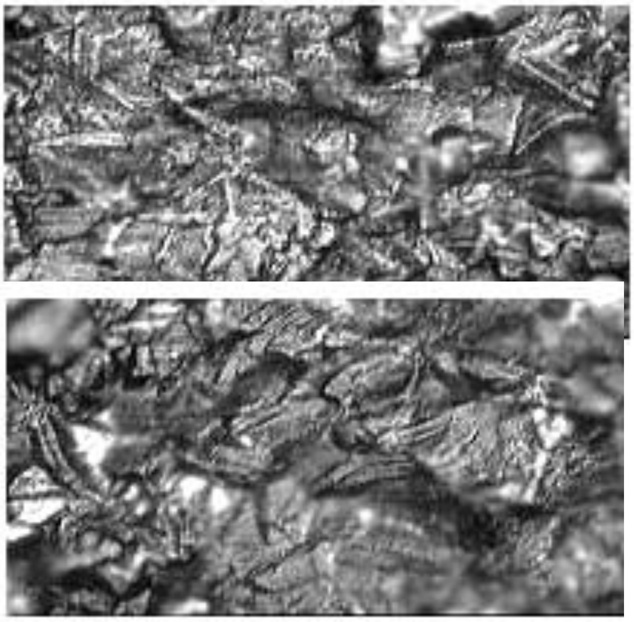


of non-hydrogen-charged samples x500

a)

b)

Fig. 7 - Relief external view in the area of initiation of neck of samples exposed to hydrogenation within 30 minutes; a) – sample previously coated with nickel, b) sample without



coating x500

a)

b)

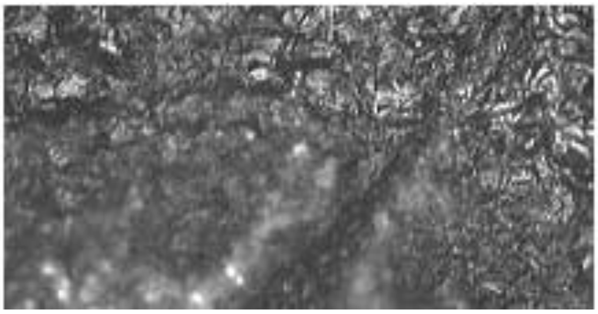


Fig. 8 Relief external view in the area remote from the initiation of neck of samples exposed to hydrogenation within 60 minutes; a) – sample previously coated with nickel, b) sample without coating x500

IV. DISCUSSION OF RESULTS

The results of X-ray crystal analysis confirm the presence of structural changes related to the presence of hydrogenous phases in the metal. However, having said that there are almost no changes in the development of deformation relief and mechanical properties. It probably stems from the fact that during hydrogenation the hydride phase is formed only at the metal surface. Stresses emerging at the formation of hydrides are concentrated in the surface layer several microns thick, which is not sufficient for the impact on mechanical properties and processes taking place in the structure in the case of breakage of the total amount of the tested sample.

At the same time, at longer hydrogenation deformation bands are observed in samples tested for tensile in the surface layer of the metal, located beyond the area of neck initiation. In this regard a significant grain refinement against the general size of titanium grain is observed in the bands of localized deformation (Fig. 8). Thus, the possibility of the impact of the level of hydrogenation on the nature of deformation relief development during titanium uniaxial tension should be noted. However, as the results of Xray crystal analysis show, the saturation of metal surface layer with titanium hydride tends to the base level. Moreover, it should be noted that there are hydride seeds in the surface layer at the initial stages of hydrogenation, and their growth and separation in an individual phase at later stages are possible.

V. CONCLUSION

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The study showed that with an increase in the duration of cathode electronic degreasing the content of titanium hydride in the surface layer of main metal increases. This results in an increase in the level of macro- and microstresses because of titanium crystal lattice distortion.

The changes of titanium hydride concentration at the metal surface depending on the duration of hydride treatment are of a fluctuating nature.

X-ray crystal analysis of samples exposed to hydrogenation and hydrogenation with following galvanic coating with nickel during uniaxial tensile test showed that hydrogenation of thin surface layer and the presence of galvanic coating have virtually no impact on the mechanic properties of the metal.

The study showed the process of appearing hydrides in the metal surface layer as a result of hydrogenation. It was noted that a growth of hydrides and their separation in an individual phase at later stages are possible. This is interesting for further studies of the opportunity to control this process and improve the quality of products made of technically pure titanium.

REFERENCES

1. R. Bendikiene, S. Baskutis, J. Baskutiene, A. Ciuplys and T. Kacinskas (December 2018). Comparative study of TIG welded commercially pure titanium. *Journal of Manufacturing Processes.* Volume 36, pp. 155-163. https://doi.org/10.1016/j.jmapro.2018.10.007
2. K. K. Chawla. Metal Matrix Composites. In: Composite Materials. Springer, New York, NY, 1998, pp. 164-211. https://doi.org/10.1007/978-1-4757-2966-5_6
3. S. Geißler, H. Tiainen and H.J. Haugen. (June 2016). Effect of cathodic polarization on coating doxycycline on titanium surfaces. Materials Science and Engineering: C. Volume 63, pp. 359-366. https://doi.org/10.1016/j.msec.2016.03.012
4. O.I. Grishina, V.N. Kochetov, A.A. Shavnev and V.M. Serpova (2014). Aspects of application of high-strength and high-modulus fiber metal composite materials for aeronautical purpose (review). Trudy VIAM: elektron. nauch.-tehnich. zhurn. Volume 10. St. 05. Available at: http://viam-works.ru/ru/articles?art_id=723
5. L.K. Ilyashenko, M.P. Prokhorova, O.I. Vaganova, Z.V. Smirnov and E.A. Aleshugina (April 2018). Managerial preparation of engineers with eyes of students. International Journal of Mechanical Engineering and Technology. Volume 9 (4), pp. 1080-1087. http://www.iaeme.com/MasterAdmin/UploadFolder/IJMET_09_04_122/IJMET_09_04_122.pdf
6. E.N. Kablov (2008). Aerospace materials science. Vse Mater. Entsikl. Sprav. 3:2-14
7. M. Khodaei and S.H. Kelishadi (November 2018). The effect of different oxidizing ions on hydrogen peroxide treatment of titanium dental implant. Surface and Coatings Technology, Volume 353, pp. 158-162.
8. E.I. Krasnov, A.S. Shtejnberg, A.A. Shavnev and V.V Berezovskij (2013). Stydy of Ti-TiAI3 laminate metal composite material. Aviacionnye materialy i tehnologii. Volume 3, pp 16–19.
9. B. Lia, J. Lia, C. Lianga, H. Lia, L. Guob, S. Liuc and H. Wang (April 2016). Surface Roughness and Hydrophilicity of Titanium after Anodic Oxidation. Rare Metal Materials and Engineering. Volume 45(4), pp. 858-862. https://doi.org/10.1016/S1875-5372(16)30088-1
10. X.P. Liabc, G. Jid, K. Edere, L.M. Yange, A. Addadd, J.V leugelsf, J. Van, Humbeeckf, J.M. Cairneye and J.P. Kruth (December 2018). Additive manufacturing of a novel alpha titanium alloy from commercially pure titanium with minor addition of Mo2C. Materialia. Volume 4, pp. 227-236. https://doi.org/10.1016/j.mtla.2018.09.033
11. M. Lukaszewska-Kuska, B. Leda, P. Gajdus and W. Hedzelek (November 2017). Evaluation of modified titanium surfaces physical and chemical characteristics. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms. Volume 411, pp. 94-99. https://doi.org/10.1016/j.nimb.2017.03.029
12. L. K. Ilyashenko, Z. V. Smirnova, O. I. Vaganova, M. P. Prokhorova and N. S. Abramova (April 2018). The role of network interaction in the professional training of future engineers. International Journal of Mechanical Engineering and Technology. Volume 9 (4), pp. 1097–1105. https://www.iaeme.com/MasterAdmin/uploadfolder/IJMET_09_04_124/IJMET_09_04_124.pdf
13. Yu. P. Sharkeev, E. V. Legostaeva, Yu. A. Eroshenko, I. A. Khlusov and O. A. Kashin (April 2012). The Structure and Physical and Mechanical Properties of a Novel Biocomposite Material, Nanostructured Titanium–Calcium-Phosphate Coating. Composite Interfaces. Volume 16 (4-6), pp. 535-546. https://doi.org/10.1163/156855409X447174
14. P. Singha, H. Pungotrab and N.l S. Kalsib (October 2017). On the characteristics of titanium alloys for the aircraft applications. Materials Today: Proceedings. Volume 4(8), pp. 8971-8982.
15. Z. V Smirnova, M. L. Gruzdeva and O. G. Krasikova (2017). Open electronic courses in the educational activity of the university. Vestnik of Minin University. Volume 4(3). https://vestnik.mininuniver.ru/jour/article/view/698/627
16. B.Szaraniec, K. Pielichowska, E. Paca and E. Menaszek (December 2018). Multifunctional polymer coatings for titanium implants. Materials Science and Engineering: C. Volume 93, pp. 950-957. https://doi.org/10.1016/j.msec.2018.08.065

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