MANUFACTURE OF RODS OF SINTERED TITANIUM ALLOYS BY USING DIFFERENT METHODS OF WELDING (Review)

A.V. OVCHINNIKOV
Zaporozhie National Technical University
64 Zhukovsky Str., 69063, Zaporozhie, Ukraine. E-mail: glotka87@ukr.net

Presented is the state-of-the-art of production of semi-products and products of titanium and its alloys in Ukraine. The rod of titanium and its alloy is one of the mostly demanded semi-products. In Ukraine the titanium rods are not manufactured in principle. For its mass production it is necessary to reduce the cost of technology for their production. The production of rod semi-products by using methods of powder metallurgy in applying of powders with the developed surface and welding was grounded. Peculiarities of application of different methods of welding were considered, the application of pressure welding was shown as challenging. The optimum one is the rotation friction welding for production of rod semi-products. The main problems, which may occur in friction welding of sintered semi-products, were considered, the need in further investigations of weldability of the given semi-products was shown. 51 Ref.

Keywords: *titanium, powder metallurgy, pressing, sintering, welding, semi-product, rod*

One of the largest consumers of titanium is the aerospace industry in manufacture of civil and military aircrafts, and this tendency is more increased. The world application of titanium in aerospace industry in 2013 was 46 % [1], while in 2006 it did not exceed 40 % [2]. Moreover, up to 70 % of parts in aerospace engineering structures have up to 30 mm section and up to 25 % of parts have up to 50 mm section [3].

The rod is the main semi-product for manufacture of blade pieces [4] and fastening parts (screws, bolts, nuts, plugs) [5], as well as springs [6]. Rods of unalloyed titanium are used for manufacture of naildrawers and crow bars for the Ministry of Emergency Situations medical instruments, implants, casings and membranes of tensoresistor transducers, stop valves and other products.

To produce the semi-products of such sections of titanium alloys, having high values of strength, it is necessary to perform deformation at high values of specific upsetting forces and at high temperatures, thus causing application of high-power and expensive equipment, and also leading to losses of metal in removal of surface layers [7]. This is partially explaining the fact that at concentration in Ukraine of about 20 % of world resources of titanium the casting and rolling productions are not enough developed, only tubes and hot-deformed rods of 10–90 mm diameter are produced [8]).

In Ukraine, the metallic titanium in ingots is produced by Zaporozhie Titanium-Magnesium Works, PWI Research & Production Centre «Titan», International Company «ANTARES» and «Strategy BM» Ltd. in billets of section: round ingots of diameter from 200 up to 1100 mm and slabs from 150 × 500 up to 400 × × 1350 mm [9, 10]. The main part of titanium resources is exported in the form of raw material [11], and the national industry is mainly oriented to import, that puts Ukraine into dependence on foreign suppliers of semi-products and ready products of titanium and its alloys [9], thus reducing the financial stability and compatibility of the national manufacturers. At the same time, the tendency to concentration of production and consumption of titanium inside the country is observed in other countries [12].

The production of semi-products and products includes, except the cost of material, the cost of technology of their producing and cost of subsequent treatments: thermal, mechanical, deformational [13]. High cost of titanium rods is predetermined by the complicated technology of their production [14]. Thus, the search of ways for reducing the costs at all the stages of production is necessary.

Application of inexpensive material can reduce the cost of the product to 20 % [15]. Up to 14 % of cost of semi-products of titanium alloys fall to melting and up to 52 % — for producing rolled metal [16], i.e. more than 65 % of cost of semi-products can fall to technologies of producing. Therefore, the main way of reducing the cost of semi-products of titanium alloys is making cheaper the technology of their producing, but not deteriorating quality of semi-products [17].

The powder technologies are the most challenging methods for processing the titanium raw material [18–20]. In applying of these technologies the number of required operations is reduced and high-efficient equipment is used [21], the parts during pressing into the required shapes are manufactured more quickly at a little machining and less wastes [22], it is possible to produce new materials with characteristics, which are often impossible to obtain by other methods [18, 23].

The reducing of costs and improving the manufacturability of producing semi-products can be provided by using granular metallurgy [21, 24–26] or even more economical methods of powder metallurgy by using powders with a developed surface [27–29]. These technologies are successfully used for manufacture of parts in different branches of industry: automobile- and avia engine construction [30]. However, the manufacture of long semi-products, to which the rods are referred, is rather problematic by powder technologies.

One of the most effective and widely spread methods of titanium alloy joining is welding [31]. Therefore, the problem of producing rods from sintered titanium can be solved by applying the advanced technologies of welding production [32], moreover, the manufacture of parts of medical purpose also admits the application of welding [33]. Technological potentials of welding process and level of mechanical properties of welded joints have a great influence on the volume of industrial application of titanium.

The proper selection of welding method predetermines the quality and efficiency of the welded joint fulfillment [34, 35]. One of the main requirements to the advanced structural titanium alloys is the assurance of ratio of the weld strength to the base metal strength of not lower than 0.9 [34]. It was earlier considered that the fusion welding even at additional effect is not capable to provide the strength factor of the welded joint of more than 0.9 [36]. The recent investigations show that the strength factor in argon arc welding makes 0.93–0.97 [31], and in argon arc welding into narrow and traditional gaps with reinforcement [37] the full strength of titanium alloy welded joints is provided. The full strength is also provided in fusion welding by the concentrated power sources: electron beam [37–39], laser [40, 41] and plasma [41]. However, these methods have a number of technological and economic drawbacks, typical of all the methods of liquid-phase welding. Methods of pressure welding can join the semi-products in solid phase for relatively short period of time, that allows minimizing the above-said effect and retaining the physical-chemical characteristics of weld metal close to the base metal [42].

In particular, the friction welding allows making the quality welded joints of titanium alloys, the mechanical properties of which are at the level of the base metal [36, 43, 44], simplifies greatly the technology of preparation for welding of titanium and its alloys as compared with the fusion welding, reduces effect of edge preparation of parts for welding, eliminates the negative effect of filler wire on the welded joint quality [35, 45, 46], and admits the absence of gas shielding of welded joint and the part [47]. In addition, the problems of noticeable shrinkage and feasibility of initiation and propagation of cracks in HAZ metal of sintered material, subjected to fusion welding, are leveled [47].

At the same time, the application of as-sintered alloys in welding can lead to the presence of inadmissible inherited defects in weld and near-weld zone caused by imperfection of the initial semi-product [46, 48]. Control of content of impurities entered from the environment is required to prevent the degradation of properties [49], the additional saturation of weld with oxygen, nitrogen and hydrogen as compared with that of base metal is inadmissible [48].

The porosity can also change the mechanism of heat transfer and, finally, the welding parameters [50]. In particular, the fraction, size, distribution and morphology of porosity have a great influence on weldability [47]. It is known that the porous titanium products can be successfully welded by the argon arc welding and some methods of pressure welding [23], but there are no almost similar investigations on friction welding, in particular, on conventional one which is especially urgent for welding of semi-products in the form of bodies of rotation. In this connection, it is necessary to carry out the investigation of weldability for the wider application of titanium, as it has a special importance in manufacture of long semi-products [39], sintered titanium semi-products, produced by the friction welding.

Actuality of works in this direction predetermined by the national and world strategies and tendencies of progress of aircraft, space, nuclear, chemical, medical and other industry branches, actively consuming the products of titanium and its alloys [51].

Thus, the analysis of the state-of-the-art of production of rod semi-products of up to 50 mm section and products of its alloys in Ukraine showed the dependence of the country on foreign suppliers. The effective method of reducing the cost of rod semi-products of titanium alloys by updating the technology of their producing was grounded. The actuality of producing rods of titanium in Ukraine from sintered titanium semi-products by using methods of powder metallurgy and welding was outlined. The need was defined for the further investigations on determination of weldability of the sintered titanium alloys.

1. Leder, O.O., Kurochkin, D.A., Alabusheva, M.O. (2014) State-of-the-art of titanium market in 2013 and tendencies of its development. In: *Proc. of Int. Conf. on Ti-2014 in CIS* (Nizhny Novgorod, 25–28 May, 2014).
2. Teslevich, S.M., Shvartsman, L.Ya., Zhigunov, N.N. (2007) Main trends in strategy of development of researches on improvement of technology for production of titanium semi-products and products on ZTMK. In: *Proc. of Int. Conf. on Ti-2007 in CIS* (Yalta, 15–18 April, 2007), 25–33.
3. Khorev, A.I. (2011) Fundamental and applied researches on thermal and thermomechanical treatment of titanium alloys for aviation and rocket-space engineering. In: *Proc. of Int. Conf. on Ti-2011 in CIS* (Lvov, 25–28 April, 2011), 314–321.
4. Nochovnaya, N.A., Izotova, A.Yu., Moiseev, N.V. et al. (2011) Formation of structure during isothermal stamping of blade billets from (α + β) heat-resistant titanium alloys. *Ibid.*, 38–40.
5. Ivanova, L.A., Kudryavtsev, A.S., Travin, V.V. (2009) Experience of application of high-strength titanium alloys in power equipment. In: *Proc. of Int. Conf. on Ti-2009 in CIS* (Odessa, 17–20 May, 2009), 46–60.
6. Kalienko, M.S., Savvateeva, G.V., Petren, M.G. (2013) Study of possibility for application of cold deformation and its influence on structure and mechanical properties of TS6 alloy rods. In: *Proc. of Int. Conf. on Ti-2013 in CIS* (Donetsk, 26–29 May, 2013), 189–193.
7. Skvortsova, S.V., Dzunovich, D.A., Shalin, A.V. et al. (2011) Deformability of titanium alloys at normal and elevated temperatures. In: *Proc. of Int. Conf. on Ti-2011 in CIS*, 361–363.
8. Site of production association OSCAR. *http://*oscar-tube.com
9. Galetsky, L.S., Remezova, E.A. (2011) Role of mineral-resource base of titanium of Ukraine in world. In: *Proc. of Int. Conf. on Ti-2011 in CIS*, 22–27.
10. Site of International company ANTARES. *http://*www.antares.com.ua/ru/index.html
11. Galetsky, L.S., Remezova, E.A., Kogon, E.Sh. et al. (2013) New stage in development of mineral-raw materials base and titanium industry of Ukraine. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 7–11.
12. Ivashchenko, V.I., Chervonny, I.F. (2009) Trends of reduction in prime cost of titanium. In: *Proc. of Int. Conf. on Ti-2009 in CIS*, 87–91.
13. Shiryaev, A.A., Nochovnaya, N.A., Burkhanova, A.A. et al. (2013) Prospects and possibilities in development of scarcely-alloyed beta-titanium alloys. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 14–18.
14. Kovalenko, T.A., Ovchinnikov, A.V. (2010) Influence of initial structure on fracture mechanisms and mechanical properties of submicrosrystalline titanium. *Novi Materialy i Tekhnol. v Metalurgii ta Mashynobud.*, **1**, 72–80.
15. Kolobov, G.A., Pecheritsa, K.A., Pavlov, V.V. et al. (2013) Secondary raw titanium: Efficiency of application and refining. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 119–121.
16. Telin, V.V., Ivashchenko, V.I., Chervonny, I.F. et al. (2005) Analysis of tendencies in development of technologies, manufacturing and consumption of titanium. *Titan*, 17(**2**), 62–68.
17. Antashev, V.G., Kashapov, O.S., Pavlova, T.V. et al. (2007) State-of-the-art, problems and prospects in development of heat-resistant titanium alloys for compressor parts. In: *Proc. of Int. Conf. on Ti-2007 in CIS*, 22–24.
18. Galetsky, L.S., Remezova, E.A., Kogon, E.Sh. et al. (2007) Problems and prospects of mineral-raw materials base of titanium in Ukraine. *Ibid.*, 34–38.
19. Stavitsky, Yu.L. (2007) Approval of hydrogenated titanium powder of ZTMK production in technological processes of powder metallurgy. *Ibid.*, 73–77.
20. Zyakhor, I.V., Kuchuk-Yatsenko, S.I. (2012) Friction welding of PIM heat-resistant steel to steel 40Kh. *The Paton Welding J.*, **9**, 2–11.
21. Telin, V.V., Teslevich, S.M., Shvartsman, L.Ya. (2007) Development of novel economical processes and equipment at ZTMK in technological processes of powder metallurgy. In: *Proc. of Int. Conf. on Ti-2007 in CIS*, 60–64.
22. Selcuk, C., Bond, S., Woolin, P. (2010) Joining processes for powder metallurgy parts: A review. *Powder Metallurgy*, 53(**1**), 7–11.
23. Drozdenko, V.A., Pavlov, V.A., Ter-Pogosiants, E.D. et al. (2007) Experience of production of titanium powders, powder titanium items and materials. In: *Proc. of Int. Conf. on Ti-2007 in CIS*, 149–155.
24. Ternovoj, Yu.F., Pashetneva, N.N., Vodennikov, S.A. (2010) *Semi-products and products from pulverized metallic powders*. Zaporozhie: Zaporozh. GIA.
25. Moskvichev, Yu.P., Panin, V.I., Ageev, S.V. (2013) Granular composites and efficiency of their application. In: *Proc. of Int. Conf. on Ti-2007 in CIS*, 41–47.
26. Spektor, V.S., Runova, Yu.E., Zanetdinova, G.T. et al. (2013) Effect of thermohydrogen processing on formation of structure of titanium alloy powder materials. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 345–347.
27. Ivasishin, O.M., Savvakin, D.G., Matvijchuk, M.V. (2011) Approval of hydrogenated titanium powder of ZTMK production in technological processes of powder metallurgy. In: *Proc. of Int. Conf. on Ti-2011 in CIS*, 322–328.
28. Bykov, I.O., Ovchinnikov, A.V., Davydov, S.I. et al. (2011) Application of hydrogenated titanium with predetermined oxygen content for manufacturing of products by powder metallurgy method. *Teoriya i Praktika Metallurgii*, 80/81(**1/2**), 65–69.
29. Ivasishin, O.M., Markovsky, P.E., Savvakin, D.G. et al. (2013) Effect of structure of structural titanium alloys on change of deformation strengthening in zone of local plastic deformation. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 287–296.
30. Yakovlev, M.G., Zhuplov, M.V. (2014) Increase in production and quality of processing of gas-turbine engine discs from granular materials due to the application of optimal cutting conditions. In: *Proc. of Int. Sci.-Techn. Conf. on Prospects of Development Trends of Aircraft Engine Building*, Vol. 1, 281–291. St.-Petersburg: Skifiya-Print.
31. Antonyuk, S.L., Korol, V.N., Molyar, A.G. et al. (2004) Fatigue resistance of welded joints of experimental titanium alloy T-110. *The Paton Welding J.*, **2**, 25–28.
32. Hamill, J. (2007) Weld techniques give powder metal a different dimension. *Metal Powder Report*, 62(**5**), 22–31.
33. Topolsky, V.F., Akhonin, S.V., Grigorenko, G.M. (2011) New titanium biocompatible alloys in orthopedy and stomatology. In: *Proc. of Int. Conf. on Ti-2011 in CIS*,173–176.

34. Khorev, A.I. (2007) Influence of complex alloying on mechanical properties of welded joints and base metal (α'' + β)- and β-titanium alloys. *Tekhnologiya Mashinostroeniya*, **2**, 29–34.
35. Blashchuk, V.E., Shelenkov, G.M. (2005) Fusion welding of titanium and its alloys (Review). *The Paton Welding J.*, **2**, 35–42.
36. Seliverstov, A.G., Tkachenko, Yu.M., Kulikovsky, R.A. et al. (2013) Effect of friction welding parameters on structure and mechanical properties of joints on titanium alloy VT3-1. *Ibid.*, **1**, 28–33.
37. Kuznetsov, S.V., Leonov, V.P., Mikhajlov, V.I. (2013) Resistance to deformation and fracture of welded joint zones of titanium pseudo-alloys at higher temperature conditions. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 180–188.
38. Saenko, V.Ya., Polishko, A.A., Ryabinin, V.A. et al. (2014) Electron beam welding of sheet commercial titanium VT1-0, hardened by nitrogen in the process of arc-slag remelting, and properties of produced joints. *The Paton Welding J.*, **11**, 46–49.
39. Markashova, L.I., Akhonin, S.V., Grigorenko, G.M. et al. (2012) Structure and properties of welded joints on titanium alloys containing silicon additions. *Ibid.*, **11**, 6–15.
40. Shelyagin, V.D., Khaskin, V.Yu., Akhonin, S.V. et al. (2012) Peculiarities of laser-arc welding of titanium alloys. *Ibid.*, **12**, 32–36.
41. Shabdinov, M.L., Izmailova, G.M., Dzhemilov, E.Sh. (2011) Advanced aspects in application of laser thermal technology for welding and cutting of titanium alloys. *Visnyk Khmelnyts. NU*, **5**, 31–34.
42. Taranova, T.G., Grigorenko, G.M., Akhonin, S.V. et al. (2013) Peculiarities of formation of structural and chemical heterogeneity in pressure-welded joints of experimental titanium alloys of Ti–Si–X system. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 214–220.
43. Seliverstov, A.G., Petrik, I.A., Tkachenko, Yu.M. et al. (2011) Examination of mechanical properties of VT3-1 alloy friction-welded joints. *Kompres. i Energet. Mashinostroenie*, 26(**4**), 41–44.
44. Petrik, I.A., Seliverstov, A.G., Ovchinnikov, A.V. (2014) Increase of properties of titanium alloy welded joints of rotor parts. *Aviats.-Kosmich. Tekhnika i Tekhnologiya*, **8**, 25–29.
45. Blashchuk, V.E. (2004) Titanium: Alloys, welding, application. *The Paton Welding J.*, **3**, 30–37.
46. Golub, T.V., Kashevskaya, O.N., Zamkov, V.N. et al. (1990) Density of weld metal produced by different methods of welding on VT1-0 commercial titanium. *Avtomatich. Svarka*, **11**, 31–33.
47. Edmilson Otoni Correa (2011) Weldability of iron based powder metal alloys using pulsed GTAW process, arc welding. *http*://www.intechopen.com/books/arc-welding/weldabilityof-iron-based-powder-metal-alloys-using-pulsed
48. Pichugin, A.T., Fedirko, V.N., Lukianenko, A.G. et al. (2007) Influence of annealing factors on fatigue service life of welded joints of VT1-0 and PT7M titanium alloys. In: *Proc. of Int. Conf. on Ti-2007 in CIS*, 431–440.
49. Savvakin, D.G., Matvijchuk, M.V., Gumenyak, N.M. et al. (2011) Prospects of application of alloys produced by hybrid technology for medicine demand. In: *Proc. of Int. Conf. on Ti-2011 in CIS*, 183–186.
50. Talas, S., Dogan, M., Cakmakkaya, M. et al. (2014) The effect of voltage on the arc stud welding of microwave sintered Fe + Al powder mixture. *Materials Research*, 17(**3**).
51. Khrushchov, D.P., Lobasov, A.P., Remezova, E.A. et al. (2013) Information-prediction structural-lithologic numerical models of titanium-zirconium gravel deposits. In: *Proc. of Int. Conf. on Ti-2013 in CIS*, 83–91.

Received 15.12.2014