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State-of-the-Art Processes of Titanium Tube and Hollow Die-Forging Manufacture by Russian and CIS Companies

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While the demand for tubes in titanium alloys decreased on the Russian market, VSMPO-AVISMA Corporation, JSC set and gained objectives to enter the global market with tubular products complying with the world highest quality as well as to develop the alternative production system for tubes and hollow die-forgings in titanium alloys. The latter was achieved by the use of the complete metallurgical production cycle beginning with production of the feedstock, sponge titanium, and finished by metallurgically produced semifinished products such as ingots, billets, plates, sheets, die-forgings, bars, tubes and finished products.
Titanium semifinished tubular products have become widely applied in hydraulic lines of aircraft and space systems, structural members of s and equipment for tube production.landing gears, aircraft engine shafts, steam generating systems of ship nuclear power installations, heat-exchange installations and chemical plants.
Applications of titanium alloy tube are constantly growing; hence, recently, they have been used for the offshore oil and gas production, telescopic control systems for slant-hole and lateral drilling, well surveys [1-7]. Now there are researches on applications of titanium tube for cold-tubing technologies in oil and gas production. Various applications of titanium tube required development of various titanium alloys, practices and equipment for tube production.

Keywords: *titanium, titanium alloys, intermediate hollow billet, hot rolled tube, hot extruded tube, hollow billet and die-forging, TREX, seamless cold-worked tube, welded large diameter tube, welded-cold-rolled and welded tube for heat exchangers.*

1. Introduction

1.1. Production System for Titanium Alloys Tube in Russia in the 1950-90s.

Since the commencement of commercial production of semifinished products, a wide variety of tube titanium alloys and methods of tube manufacture have been developed (Fig. 1), including production of cold worked tubes in commercial titanium with the tensile strength over 343 MPa to the medium-strength titanium alloys providing for the tensile strength 833 MPa, and hot-worked tube with the strength up to 1150 MPa.

With the planned economics and the state technical control, the integral production system for titanium alloy tube over 3 to 477 mm in diameter was established which provided for the needs of aircraft engine-building, aerospace, ship construction and consumer goods industries. Over 2000 tube dimensions and alloys [8] were implemented and commercially produced.

Hot rolled tubes and hollow billets were commercially produced using commercial titanium of grades VT1-00 (Ti-0.05C-0.04N-0.1O-0.15Fe-0.08Si), VT1-0 (Ti-0.3Al-0.07C-0.04N-0.2O-0.25Fe-0.1Si), PT1M (Ti-0.05C-0.04N-0.12O-0.3Zr), low alloy α- and pseudo-α titanium alloys of grades OT4-0 (Ti-1Al-1Mn), OT4-1 (Ti-2AL-1.5Mn), OT4 (Ti-4Al-1.5Mn), PT-7M (Ti-2AL-2.5Zr), PT3V (Ti-4Al-2V), VT20 (Ti-6.5Al-1Mo-1V-2Zr-0.15Si), and titanium α+β-alloys of grades VT9 (Ti-6.5Al-3Mo-1.5Zr-0.25Si) and VT14 (Ti-5Al-3Mo-1V) in accordance with National Standard GOST 21945-86 and special technical conditions.

Hot-rolled tubes in high-strength titanium alloys for aerospace applications were commercially produced using titanium α+β- and pseudo-β-alloys of grades VT3-1 (Ti-6Al-2.5Mo-1.5Cr-0.5Fe-0.3Si), VT6s (Ti-5Al-4V), VT6 (Ti-6Al-4V), VT23 (5Al-4.5V-2Mo- 1Cr-0.6Fe), OT4 (Ti-4Al-1.5Mn) and VT22 (Ti-5Al-5Mo-5V-1Cr-1Fe) in accordance with special technical conditions.

Seamless cold worked tubes were commercially produced from hot rolled tube in commercial titanium of grades VT1-00, VT1-0, PT1M and titanium low alloy α-and pseudo-α-alloys of grades OT4-0, OT4-1, OT4 and PT7M. Hot rolled tubes and hollow billets subjected to rolling in the β-filed had β-deformed coarse-grain structure and low ductility which posed problems both for marketable hot rolled tube and subsequent cold rolling operations.

1.2. Today Production System for Seamless Tube and Hollow Die-forging.

It is provided by the Corporation's complete metallurgical production cycle which includes melting of ingots with the specified chemical composition; processing of ingots into intermediate hollow billets; production of hot extruded or hot rolled marketable tubes, hot-rolled marketable bars and hollow billets designated for further processing; and cold rolling of tubes (Fig.2).

1.3. Improvement of Manufacturing Methods for Intermediate Billets.

Review of international standards, higher requirements for Russian tubular products, all these lead to development of the system of production of "customized" products which defines ingot chemical composition, ingot size, and selects the method of ingot processing into the intermediate billet and the finished tube complying with the required macro- and microstructure levels, mechanical and performance properties of tubular products.

Depending on requirements for the finished tube, the following deformation flow charts can be specified: simple β-forging operations of the ingot to produce the intermediate stock like bars; or complex multiple-pass

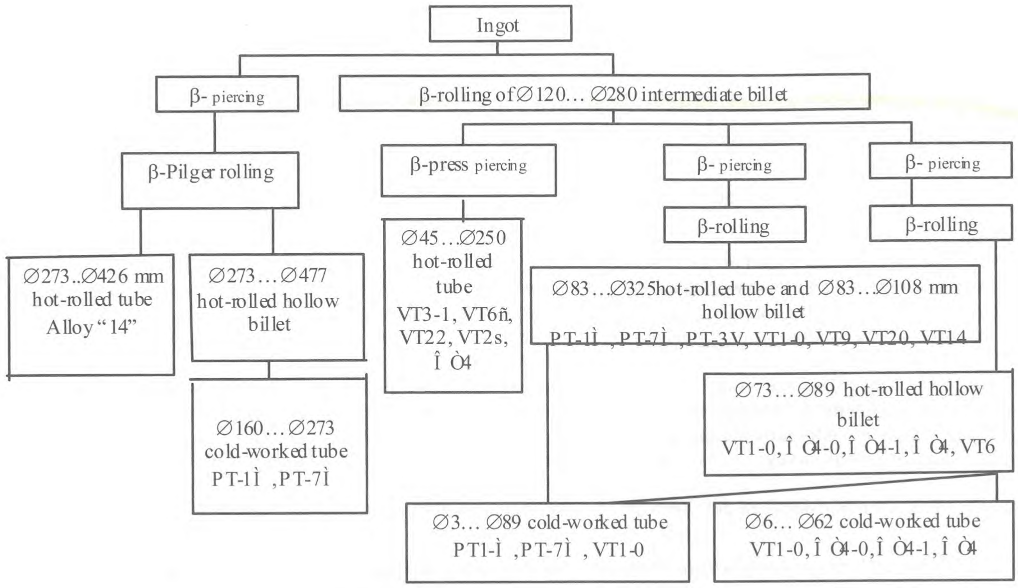

Figure 1. Production system for titanium alloy seamless tube in Russia in the 1950-90s.

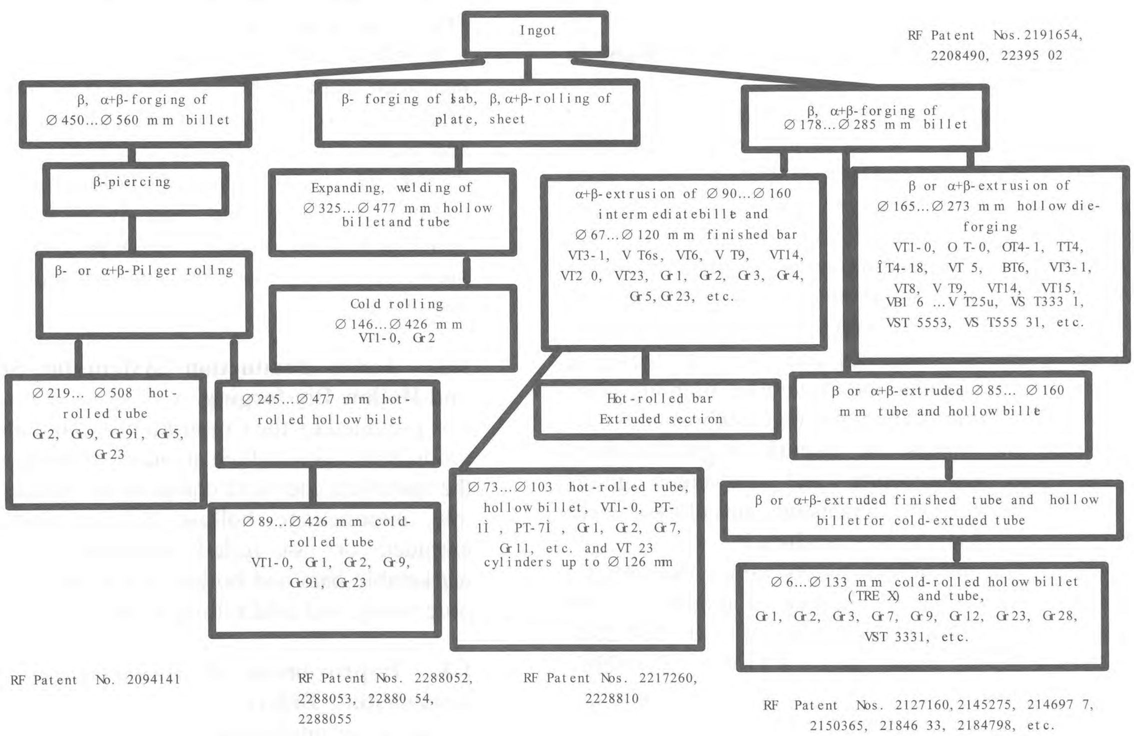

Figure 2. Production system for titanium alloy tube and hollow die-forging (new technologies).

forging operations at temperatures above or below beta transus temperature $\beta \rightarrow (\alpha+\beta) \rightarrow \beta \rightarrow (\alpha+\beta)$; or combined operations including forging of the intermediate billet and extrusion of the intermediate billet.

For production of hot rolled and hot extruded tubes and hollow billets, new methods of intermediate stock manufacture have been developed and implemented. These include extrusion of thick wall hollow billets or bars [9] in the $(\alpha+\beta)$-field instead of conventional 4-5-pass forging operations in the $(\alpha+\beta)$-field [10]. Production of the intermediate billet by using extrusion instead of forging, on one hand, decreased the labor intensity and the number of heating cycles, and, on the other hand, ensured generation of the required fine-grain structure.

The intermediate extruded stock such as bars is used either for subsequent hot rolling of tubes and hollow billets in commercial titanium and low alloy titanium or for subsequent extrusion of tubes in majority of national and international titanium alloys, including those designated for TREX hollow billets [11,12].

Based on investigations of the grain structure evolution, the highly refined homogeneous structure and the specified level of mechanical properties are ensured by selection of efficient process parameters, optimal conditions of press forging operations, extrusion of intermediate stock and production of semi-finished products.

1.4. Improvement of Manufacturing Methods for Large Diameter Hot Rolled and Cold Rolled Tube on TPA8-16 Pilger Rolling Mill, KhPT50 and KhPT250 Rolling Mills.

For production of hot rolled tubes and hollow billets with the large diameter, the method of billet manufacture was developed. It includes the forging reduction to the specified dimensions with subsequent rolling on the Pilger rolling mill. [13]

Implementation of the new production method for the intermediate billet [13],which includes preliminary forging of ingots to at least 2.7 reduction ratio and finish forging in the α+β-field to produce billets with subsequent rolling on the Pilger tube-rolling mill allowed to obtain the required grain size, eliminate transverse tears along the grain boundaries, decrease allowances for machining of the hot-rolled tube by 2.0-2.5 times, and perform subsequent cold rolling of titanium alloy tubes, including grades Gr9 (Ti-3Al-2.5V), Gr9M (Ti-3Al-2.7V-1.3Mo-1.0Zr) and Gr23M (Ti-6Al-4VELI-0.05Pd) [4-6].

1.5. Development and Implementation of Manufacturing Methods for Thin Wall Welded Cold Rolled Tube with Large and Medium Diameter in Commercial Titanium.

For oil and gas platforms, chemical and energy equipment there is the need for thin wall commercial titanium tubes 159 mm or more in diameter [7,14]. Thus, the special method was developed with its further implementation for production of ∅159-∅426 mm welded cold rolled tubes [15-18].

2. Development and Commissioning of Production Facilities for Hollow Billets (TREX) and Cold Rolled Tubes for High Tension Systems.

One of the objectives set for ensuring production of competitive products was to design and implement the manufacturing method for premium quality hollow billets (TREX) in titanium alloys for aerospace hydraulic systems [11,12].

The process of development of a new technology for the tube production and developed engineering solutions are described in articles [19,20]; and improvement approaches for TREX production are presented in the paper [21].

New technologies developed while commissioning production process for TREX allowed to establish production facilities for cold rolled tubes for high tension systems and became the basis for development of new technical conditions establishing more severe requirements for geometry accuracy and surface quality in ship construction and nuclear power industries.

3. Range Expansion of Titanium Alloy Hot Rolled Tube and Hollow Billet.

Improvement of production technologies for intermediate stock by the use of combined operations, forging + extrusion, allowed to form the fine grain structure, expand the range of hot rolled machined hollow billets from ∅ 70-89 mm to ∅ 70-127 mm, and also became the basis for development of new technical conditions for hot worked tubes up to 100 mm in diameter for nuclear power plants.

4. Development and Commissioning of Production Facilities for Titanium Alloy Hollow Extruded Die-Forging and Tube.

Historically, VSMPO-AVISMA Corporation, JSC produce hot-extruded hubs 45-160 mm in diameter and 600-1500 mm in length for further heat-treatment and machining at customers' facilities. [19]

The new approach in this segment is production of the extruded machined tube and hollow billet. This was achieved by development and implementation of new extrusion methods. [22-25, 28].

New methods and the special tooling have been developed to make possible production of hollow die-forgings with variation [26] or constant [27] wall thickness by punch extrusion using tube-extrusion presses.

5. Resource Saving Technologies in Production.

5.1 Reduction of Material Loss.

Production processes for extrusion of intermediate stock such as hollow thick wall tubes and bars include the use of rare spacer rings [22,9] which allow to eliminate extrusion discard and reduce funnels. Engineering solutions focused on piercing and expansion of billets with no wad [29], extrusion of tubular products without funnels [30,31], extending the length of billets [24], working out of outlet ends of tubes and die-forgings [22] are also aimed to reduce the metal loss during tube production processes.

5.2. Improvement of the Pressing Tool Lifetime.

In terms of energy costs, environmental issues, serviceability, toll lifetime improvement and extruded product quality, the optimal decision obtained was the use of coatings applied by the electrospark method[32]. These coatings were applied by the equipment which allowed to rotate and move the electrode relative its working surface[32, 33]. Due to addition of the titanium inert material and the specific surface geometry contributing to better lubricant holding properties, thereby improving the die thermal protection, the die after reinforcement by the use of the electrospark method allows to perform extrusion providing for a better quality of the surface of the manufactured products compared to conventional dies [34]. The lifetime of conventional dies reinforced by the electrospark method increased by 3 to 8 times (with repairs).

6. Welded Tube for Heat Exchangers.

VSMPO-AVISMA Corporation, JCS produce and supply tubular products 12.7 to 60.3 mm (0.,47" to 1.5") in diameter, 0.5 to 2.5 mm in wall thickness and up to 25000 mm in length in Gr1 and Gr2 titanium alloys for energy and chemical processing industries.

Round longitudinal welded tubes are produced from flat rolled stock (strips) using tube electric welding equipment by forming in a special tool [35] and automatic tungsten-arc welding in inert gas (argon) with subsequent heat treatment in the mill line.

7. Conclusions:

1. The issues of entering the global market, increased requirements for tube quality, the need for development of alternative production technologies for titanium alloy tube and hollow die-forging were successfully addressed by VSMPO-AVISMA Corporation, JSC personnel in cooperation with allied partners and other institutions of Russia.
2. The new production system for titanium alloy tube and hollow die-forging has been developed which expands the range of produced tubular products depending on alloys, dimensions and quality.

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