PRINCIPLE TRENDS OF INVESTIGATION IN THE
FIELD OF TITANIUM PRODUCTION

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Titanium Industry in the USSR

The time of holding the Fourth International Conference on Titanium almost coincides with the 30th anniversary of the beginning of research work on titanium in the USSR. In this period of time specialized workshops and plants have been built in our country, technological processes developed, and production mastered of a wide range of ingots and semifabricated products in commercial titanium and various titanium alloys which are successfully utilized in many industries.

There is a great demand for titanium, especially in chemical engineering, in coking by-product equipment and blast furnace construction, in nonferrous metallurgy, and some other industries. The application of shaped castings as fittings is of great interest. Interesting results have been obtained in chemical engineering and oil-and-gas industry. Specialists of E.O. Paton Electric Welding Institute have achieved great success in this direction. The application of titanium not only promotes technical progress, but also gives really high efficiency in national economy. Thus, according to calculations, the application of 1 ton of titanium in civil industries gives economy equal to 9,000 roubles.

Also, it must be mentioned that during the whole period of development, including the last years, titanium output has been constantly increased in the USSR which has promoted the improvement of production and consumption economy, thus constantly reducing the cost of rolled titanium.

The resources of the Soviet industry as to the manufacturing of various products, such as sheets, plates, rods, bars, wire, tubes, sections, panels, and forgings are constantly growing. The dimensions of products are being increased, their new types and shapes are being mastered, the shape configuration is being complicated, and the precision is being improved. Thus, for the last years the range of extruded products has been largely extended and their quality improved.

The application of complex technology for their production, including hot extrusion with subsequent sizing on presses of pulsating loading or on rolling-sizing mills with higher axial and radial rigidity, permits production of high-precision thin-walled sections with minimum thickness of 0.8 to 1.0 mm, thickness deviation ±0.2 mm and surface roughness 6.3 μm.

The production of thin-walled shapes having holes of looping type and passages of complicated configuration, as well as shapes of variable section has been further developed. Considerable progress has been achieved also in expansion of the range of forgings and improvement of their accuracy. The manufacture of welded rings out of sheets and other techniques has been broadly developed.
Great attention in the Soviet Union was and is paid to the improvement of mechanical properties and other factors characterizing the quality of products.

A very important trend developed from the beginning of industrial production of titanium and its alloys consists in lowering or limiting the content of gas impurities in semiproducts. This is achieved by improving the purity of sponge and alloying elements, by better scrap preparation, by using protective coatings when heating, by application of effective means to clean the surface and by using vacuum annealing. During 15 years the gas content in sponge has been lowered, as well as the gas content in finished products.

The structure of semifabricated products is of great importance from the point of view of durability of titanium-alloy parts. This is connected with very high sensitivity of their mechanical properties to structure. Depending on customers' requirements to properties, we can provide one of three types of structure according to the production technique: with primary α-phase of globular shape, with globular - laminar α-phase, or with laminar α-phase. Thorough control of production technique as well as of semiproducts is a reliable guarantee for their quality.

Among the methods of quality control we can mention composition analysis, ultrasonic tests of ingots, preforms and semiproducts, X-ray and luminescent tests, macro- and microstructure analysis, investigation of mechanical properties, including—if necessary—rupture strength, fracture toughness, fatigue resistance and other characteristics, and some other special tests.

At the 3rd Conference on Titanium it was mentioned that for the whole history of titanium development high cost of its production and processing as a result of specific technology was one of the obstacles towards its wide application in national economy. It is therefore natural that efforts of scientific and industrial organizations in the Soviet Union were directed towards the solution of the following problems:

1. Removal of the limit for secondary metals and scrap recovery when melting titanium alloys, which was about 25% (as it was stated at the 3rd Conference), and resulted in higher coefficients of titanium sponge consumption.
2. Increase of the yield when processing titanium alloys in metallurgical plants.
3. Reduction or making easier machining of titanium products which are more labour-consuming, as compared to those of aluminium products.

The most significant results have been achieved in melting and casting processes, hot isostatic pressing of powders, and diffusion bonding technique.

Titanium Melting and Casting

Production of Cast Billets

In the USSR there has been developed a new technology and equipment for production of titanium ingots. Ingots of first melting are produced in scull furnaces with consumable scull.

The advantages of scull melting are as follows:
- the possibility of including practically unlimited amount of scrap into charge, and preparation of ingots out of 100% scrap;
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- reduction of labour consumable preparation of scrap as its refinement is not required any longer;
- elimination of extruding a consumable electrode from sponge;
- the possibility of producing alloys with high content of refractory components;
- improvement of homogeneity of metal composition;
- elimination of the possibility of formation of inclusion-type defects;
- 1.5 to 2 fold rise in productivity;
- reduction of titanium sponge consumption.

This process permits melting metal and preparing billets for remelting. In the future it might be possible to produce finished billets for subsequent hot working. For this it is necessary to solve the problem of averaging the composition and to design necessary means for casting round, square, or rectangular ingots in accordance with the production requirements.

The most significant peculiarity of this technique consists in including secondary metals into the charge, but today's setting of the process does not exclude casting of large round ingots for billets used in commercial press-forging production and in forging slabs for rolled sheet production.

The skull melting process permits solving this problem only if the remelting is carried out as an electroslag melting, developed in the USSR. The melting is accomplished in an argon atmosphere in vacuum under alternating current into a D.C. mold. Pure calcium fluoride is used as a slag, and the melting process itself is similar to the process for electroslag melting of steel.

The electroslag melting technique permits production of commercial billets and slabs directly during the melting and avoids the rolling of large round ingots into billets and slab forging, due to which the yield is increased by 10 to 15%. The ingots after melting have smooth surfaces and require practically no machining prior to deformation.

Hot Isostatic Pressing

Extensive work has been done in the field of compacting powder metal into a solid part, the properties of which are higher in comparison with those produced by a conventional method. The success is mainly determined by the method of powder preparation. Centrifugal atomization of a rotating electrode is the most widely used method in our research and development work.

Simultaneously we have investigated the possibilities of other techniques aiming at the creation of commercial-scale units for production of high-quality powders with high yield.

Version 2 is similar to the 1st version, but the lower consumable billet is replaced by a cup-granulator.

The last version seems to provide the production of a more uniform powder, as averaging of the melt composition takes place in the intermediate container.

The most important aspects of the process are as follows: powder refining and processing, designing and manufacturing of capsules and, certainly, compacting. As a rule, compacting is carried out in hot isostatic presses.
In powder pretreatment, its degassing is quite important. Capsule designing and manufacturing, as well as its filling and evacuation, is another complicated problem. One needs time and experience to master the process of manufacturing capsules which are complex in shape and accurate in dimensions, and to find laws for forming a compact during hot isostatic pressing of capsules made of different materials.

Powder preform of a gas turbine compressor disc made in a steel sheet capsule has much lower mass than a die-forging.

A structural component in a P/M high-strength titanium alloy with maximum dimension of 500 mm was manufactured using a capsule with insert elements, which permitted the production of rather thin ribs without bias.

Manufacturing of such components by a conventional forging technique or even isothermal forging presents large technical difficulties.

Application of P/M methods provides significant reduction in raw metals consumption. The largest saving of raw metals can be achieved when producing near-net-shapes just after HIP.

Mechanical properties of powder HIPed preforms exceed those of castings and are close to those of wrought metal.

Accumulated data and the scope of research and development work on the problem of powder titanium alloys permit us to hope that in the near future this technique will take one of the leading places in production of near-net-shapes.

The most economical is the P/M production of parts of complex configuration, which are now produced by machining of die- and hand-forgings.

In the future, as powder production and compaction techniques develop, powder metallurgy will be effective in production of sheets, tubes, and other semiproducts of titanium alloys.

**Diffusion Bonding**

For the last decade in aircraft construction there has been a great demand for complex large-size titanium structures, the production of which by traditional methods (mainly by machining) is labour-consuming and expensive.

Application of diffusion bonding allows us to decrease the machining labour consumption by 3 to 5 times, to raise the metal utilization factor by 2 to 4 times, and to cut the parts cost considerably. Moreover, this process is promising for the improvement of aircraft characteristics due to the possibility of creating original structures with special properties (e.g. out of dissimilar materials).

Diffusion bonding of titanium alloys is carried out in a vacuum of $10^{-4}$ to $10^{-5}$ torr and a temperature range of 900 to 950°C. The pressure and time for bonding depend on the type of product, the structure and phase composition of the alloy, and can be changed within a wide range. There are various methods of loading, the most widely used are press, isostatic, and thermo-compression methods.
The installation for diffusion bonding of titanium alloys includes a vacuum heating chamber and a hydraulic press. The installation provides a vacuum of $10^{-4}$ to $10^{-5}$ torr during the whole process, as well as uniform distribution of temperature along the surface to be bonded with deviation from the preset temperature within ±10°C, and rather uniform load transfer on the bonding area. The press method seems to be the most efficient for manufacturing semiproducts and parts with large bonding area, the production of which requires rather big total forces.

When using the isostatic method, a part to be bonded is assembled in a special device and is put into an evacuated air-tight container made of thin-sheet steel. The force is applied through compressed inert gas or a liquid medium heated up to a given temperature. The benefit of this method lies in the availability of volumetric uniformly distributed pressure which permits bonding the part along the different surfaces providing close size tolerances.

The diffusion bonding technique allows production of parts with no residual stresses, with joints, the strength of which is equal to that of the base metal, and with homogeneous structure in the bonding zone. The bonding zones of the panels do not have microdiscontinuities. Complex static and fatigue tests have shown that the joints have a property level close to that of solid specimens of the same configuration with the same type of fracture along the base metal.

The work of E.O. Paton Institute of Electric Welding has shown that diffusion bonding can be successfully used for production of parts having massive elements and large surface areas.

Thus, the diffusion bonding technique, providing production of parts with high-quality joints, is an efficient method of economic production of semiproducts and parts in titanium alloys of complex shape and large sections. With appropriate corrections of some operating conditions, the process has no limit as to the phase composition and structure of alloys although two-phase materials with fine structure have the best weldability.

New Production Processes: Improvement of Mechanical Properties and Structure

Isothermal forging cannot be included among the developments of recent years. However, the most significant contemporary requirement, i.e. the improvement of economic factors in titanium production, allows us to count this process as one of the most progressive processes. Tool life remains an unsolved problem.

Perfection of heat treatment conditions and techniques has permitted us for the last 10-15 years to improve constantly the properties and structure of titanium alloys. By accelerated heating one can considerably increase the level of mechanical properties and improve the structure of titanium alloys. The large amount of research work devoted to the problem of improvement of mechanical properties and structure by heat treatment, conducted recently throughout the world, can be regarded as an indication of the importance of this trend in the future.

The work on manufacturing semiproducts by the vapor deposition method is of interest. This method consists of heating the alloy of a certain
composition up to the temperature of its evaporation and condensation on a
cold substrate. It permits the production of titanium semiproducts of any
configuration having thickness from several microns to several milimeters.
Fast condensation on the substrate provides a finegrained structure, guaran-
teeing a high level of mechanical properties in products.

A large number of investigators in many countries are now occupied with
the development of new titanium alloys. The main progress in this field,
though, has been observed recently in the improvement of production techniques,
alloy composition and heat treatment conditions, rather than in the development
of new alloys. However, in our opinion the development of powder metallurgy
will stimulate in the very near future a jump in this direction, and some
new work aimed at the creation of new high-temperature alloys based on inter-
metallics, as well as special alloys produced under high-rate solidification,
and alloys permitting variable composition along the product section will
appear.