1. Introduction

After nearly 35 years of successful classical titanium ingot production (1, 2), it is time to think about new methods for virgin material making, scrap reclamation, semiproduct manufacturing, new qualities of ingot structure and new methods of Ti-alloy development.

The scope of our new concept is: Reduction of several manufacturing steps requiring many equipments to a combination of those in one or two steps and in processcontrolled machines. The decisive tools of the new processes are: Programmable electron beams and movable low pressure plasma torches. Final goals are: Saving process energy, increasing material yield and improving material properties.

2. New Methods for Manufacturing of Semiproducts.

2.1 Multi-Barstick Continuous Casting.

Instead of second VAR ingot melting and rod production by hot forging, rotary forging or extrusion, electron-beam continuous flow melting followed by multi-barstick continuous casting can be considered. The principle arrangement of EB-guns, refining and liquid metal distribution trough and continuous casting mold is shown in fig. 1. The first trials of twin ingot casting have been carried out in a 200 kW EB-furnace (fig. 2) with Ti 6Al 4V, and are shown in fig. 3. The structure of one of the two twin ingots of 73 mm dia. is shown in fig. 4. Casts in a 75 mm dia. mold are inspite of the larger ingot withdrawal speed equivalent to those of a VAR melted one of simi-
lar dimension. Machining of the twin ingot - in order to obtain a smooth surface for application as rotary electrodes for powder production in a REP or PREP machine - reduces the yield from 98 % to 97 %.

Results gained in the first trials allow us to present a concept of a process and equipment for continuous casting of 18 barsticks of 60 to 75 mm dia. (fig. 5). High material yield of the raw barsticks, low specific melting energy and high productivity should result in a reduced price for titanium rods. Losses of aluminum can be compensated by controlled addition of Al-granules into the melting pool close to the consumable electrode, such that homogenization takes place in the trough pool.

Fig.3 Melting of 75 mm Ti 6Al 4V Twin Ingots at 91 kgh⁻¹ and 147 kW

Fig.4 Cross Section of one of the two Ingots of 73 mm dia.

Fig.5 Concept of a Multi-Barstick Continuous Casting Furnace

Expectable Processing Data
Barstick size: Diameter 65 or 75 mm
Length 1600 mm
Production rate: 600 kgh⁻¹
Specific Melting Energy: 1 kWh kg⁻¹

2.2 Fine Grain "Cake" and Ingot Casting.

The development of new alloys is often limited by segregation phenomena when melting large ingots in VAR furnaces. Production of ingots with very fine, homogeneously distributed grains could be a method to reduce or eliminate segregation and to reduce forging problems and costs (3). Some trials carried out in the furnace shown in fig. 2, with EB-gun, melting trough- and rotary mold arrangement shown in fig. 6, have indicated that within a certain combination of melt rate, trough pivoting speed and mold rotation speed cakes of 250 and 400 mm dia. and 80 resp. 60 mm thickness can be made with a grainsize that is significantly smaller than that of an
equivalent VAR ingot. We have learned that fine grain cake production of Ti-alloys, shown in fig. 7, is somewhat more difficult than that of Nickel-base superalloys. Although the Ti-alloy cake does not have the same fine grain structure as the IN 718 cake section, shown in fig. 8, we are optimistic and believe that cakes and later on ingot structures can be achieved, which will be equivalent to PM manufactured ones regarding segregation and microporosity, but should have the advantage of much higher cleanliness, better material yield and lower manufacturing costs. This new method, principally shown in fig. 9, offers the production of ingots larger in diameter and weight than attainable with the conventional method without limiting the properties of forgeability.

Fig. 6 Melting of 250 mm dia. Ti 6Al 4V Fine Grain "Cake" at 70 kg/h with 135 kW.

Fig. 7 Inside of Meltchamber after Melting of 250 mm dia. Fine Grain "Cake".

Fig. 8 Cross Section of Several Fine Grain "Cakes" from the First Trials.

Fig. 9 Concept of a Fine Grain Ingot and "Cake" Melting Process. Ingot Ø 1.2 - 1.5 m; Weight 17 t; Melt Rate 2,500 kg/h; Specific Melting Energy 0.6 kWh kg⁻¹.
2.3 Thin Slab and Heavy Sheet Production.

With the same technological philosophy as for manufacturing of multi-bar-sticks and fine grain ingots, economical production of thin slabs and heavy sheets have been considered and concepts elaborated. Basic trials to confirm the principal ideas of these new processing routes have not yet been carried out and, therefore, these methods cannot be discussed in this paper.

3. Production of Ti-Alloys from Aluminothermite Virgin Titanium and Ti-Scrap.

The production of reactive and refractory metals, e.g. vanadium, niobium and on a small scale zirconium (4), from the corresponding aluminothermite material by distillation of the aluminum in an electron beam furnace is common practice and allows us to consider to transfer this method with some modifications to the making of Al-containing titanium alloys. The scope of the shown procedure is to reduce the number of processing steps and to combine the distillation process and scrap recycling process in one piece of equipment. Keys to this new method are again: 100% control and automation of the process, accurate power distribution to those locations where the heat is required and continuous control of the alloy by "in situ" analysis of the metallic elements plus fast sample taking and analysis of interstitial elements.

![Diagram of Ti-Alloy Production from Al-Thermite Ti and Ti-Scrap](image)

The process steps for the production of aluminothermite titanium in a Vacuum Induction Furnace under a certain level of argon pressure to achieve a low oxygen and nitrogen content and the subsequent steps to separate the thermite material from the slag are shown in fig. 10. The key of this procedure is the use of titanium-containing aluminum-condensate collected in the EB-distillation furnace, the use of clean TiO₂ from pigment production and the automated mechanical separation of slag from the thermite material. The required processing energy should be in the range of 25 - 30 kWh per kilogram titanium, if the process is carried out in a furnace of optimum size.

Distillation trials carried out in a laboratory furnace and in the 200 kW EB-furnace, shown in fig. 2, and experiences gained with Al-distillation from aluminothermite Zr in EB-furnaces of up to 1,200 kW, shown in fig. 11 and 12, allow the assessment of some processing data for a proposed production furnace. The concept of such a furnace limited for production of Ti-alloys with Al-contents of more than 4% is shown in fig. 12. The limitation is given by the potential increase of production costs, when more aluminum has to be removed.
Fig. 11 Schematic Figure of a Thermite Distillation Furnace

Fig. 12 EB-Pilot Production Furnace for Distillation of Zr Al and Ti Al

Fig. 13 Concept of an EB-Melting Furnace for Refining of Ti Al Thermite and Recycling of Scrap, Blended with Sponge for the Production of Fine Grain Ingots

Calculated Annual Production: 1,400 t

Provided EB-Power: 5,000 kW
The total process is divided in four sections:

a) EB-Melting of thermite material, skimming of the remaining slag with a mechanical barrier and distillation of the aluminum.

b) EB-melting and refining of selected scrap (solids and turnings) and sponge with alloying elements.

c) Homogenization of clean raw material and upgraded scrap with continuous control of the alloy content by "in situ" metallic element analysis and fast sample taking combined with analysis for interstitials and adjustment of the alloy content by adding of the missing element quantities in the last trough, where homogenization takes place.

d) Solidification of the melt can be carried out in a shallow pool continuous casting crucible, as shown in fig. 12, or by fine grain ingot casting or multi-barstick casting shown in the figures 9 and 5.

4. Production of Ti-Alloy Ingots or Slabs in the Low Pressure Plasma Furnace.

4.1 Scrap Recycling and Continuous Casting of Slabs.

Scrap recycling carried out by continuous flow melting in EB or plasma furnaces have been proven as reliable, accessible melting methods (5). Both are burdened by disadvantages: The EB-method by selective, intensive Al-evaporation and high energy consumption of the required vacuum equipment, plasma melting method by insufficient reduction of hydrogen and chlorine, when sponge has to be added to reduce the high oxygen-content of scrap turnings.

The development of a heat source which combines the positive properties of EB and plasma heat source is the low pressure plasma torch, precisely movable in x, y and z direction and turnable around a y-axis. It allows the optimum distribution of energy by accurate positioning of the torch above the melting area. These torches are operating at a vacuum level where hydrogen and chlorine will be removed with the necessary efficiency without loosing aluminum by evaporation. The concept of such a continuous flow low pressure plasma furnace is shown in fig. 14.

Fig. 14
C. P. Titanium Overflow Melting in a Hearth and Continuous Casting of Slabs
4.2 Scrap Refining and Upgrading by Melting in Large Water Cooled Copper Crucibles.

All known Ti-scrap recycling methods are semi-continuous melting processes. Material to be melted must be of a well known quality to allow the production of a high quality ingot, slab or consumable electrode for VAR-melting. However, a large amount of scrap - approx. 30% of the total scrap market - is of uncertain quality and cannot be used for the production of qualified titanium. Our new concept (fig. 14 + 15) of a low pressure plasma furnace

Fig. 15 Ti-Alloy Melting, Analysing and Alloying with 3 Low Pressure Plasma Torches of 1,000 kW each, Liquid Metal for Pouring over the Lip 1.5 t

Fig. 16 Continuous Casting of 1,500 kg Liquid Ti-Alloy for Production of a Slab of 1,000 mm Width, 200 mm Thickness and 1,700 mm Length with constant Superheating of the Pool
allows melting of large quantities of scrap of any reasonable size and qua-

lity in a water cooled copper crucible with three movable plasma torches. After melting of the charged material, samples can be taken and after the analysis is known, material can be added and the alloy composition can be adjusted. After a second sample and confirmation of the alloy composition, the melt can be slowly poured into a continuous casting mold. During the entire slab or ingot withdrawal cycle, the melt in the copper crucible will be kept liquid with one of the three torches, the other two torches can be directed to the pool in the continuous casting mold to achieve the required slab or ingot structure.

5. Conclusion

Five different melting concepts for the production of Ti-alloy semiproducts and ingots of special grain size have been introduced and discussed. All of them have the chance to be developed and applied in profitable large scale production for titanium parts. They are based on heat sources of highest flexibility, power efficiency and controllability, such that material qua-

lity and productivity can be guaranteed. Aspects are given to increase the production efficiency which is a basic requirement for new applications and replacement of other materials and thus for an enlargement of the titanium market.

6. References

(3) Fine Grain Ingot Structure
(4) EB-Melting of Refractory Metal Ingot from Aluminothermite Material
(5) Refining of Ti-Scrap in Plasma- and EB-Melting Furnaces