State of the Art in Electron Beam Melting of Titanium

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Abstract

The electron beam cold hearth melting (EBCHM) process has developed into a premier refining tool for both aerospace and industrial titanium applications. Hearth refined titanium has now been specified in critical jet engine components. Improved levels of quality control are obtained by maintaining close control over such operating parameters as electron beam energy distribution, condensate management, and chemical homogeneity. Advances have been made in near net shape castings of preforms (semi's) for the direct rolling of as-cast titanium slabs.

"MaxiMelt," the world's largest electron beam cold hearth furnace (3300 kW - 915 mm diameter ingots) has recently been commissioned at Axel Johnson Metals, Inc. Start up and qualification programs for this new furnace are discussed.

Introduction

Since the time of the Sixth World Conference on Titanium, numerous developments have occurred in the Electron Beam Cold Beam Hearth Refining (EBCHR) process for titanium. During the Sixth World Conference, some of the initial work on "in-spec" alloy electrodes and near net shape casting was presented. Developments were also reported in the areas of on-line chemistry and intelligent materials processing. (1)

During the last four years, the EBCHR process has continued its steady evolution into a premier refining tool for both industrial and aerospace titanium applications. This paper is intended to review the current status of high-volume commercial products such as large slabs and refined alloy electrodes. It will also present a brief history and current status of the world's largest operational electron beam furnace, MaxiMelt, which was built and commissioned during the last four years.

New developments in controls, instrumentation, and operating practices are continuing to occur. This paper will also highlight these areas for future growth.

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It can be seen from Table 2, that there is an overall decrease in the concentration of carbon and hydrogen in the remelted ingot. In the case of nitrogen, the remelted materials show a little higher concentration than in the electrode. There is no additional oxygen pick-up during remelting. It must be mentioned that the values of oxygen and nitrogen content in the electrodes are probably not representative of the whole electrode. It is evident, that all values are within the ASTM-specification for Grade 1 titanium (CP).

Conclusions

- Electroslag remelting is an efficient process for the consolidation of titanium.
- It appears that a single melt will be sufficient for further working.
- With proper process control, any additional pick up of undesired elements, like oxygen and nitrogen, can be completely avoided.

Literature

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Metal Bulletin Monthly, August 1991, pp. 28 to 33

/ 2 / S.M. Gurewich and Co-workers
"Properties of Technical Grade Titanium and OT4-Alloys Produced by Electroslag Melting" Automatic Welding (1963), Vol. 16, pp. 20 to 21

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Tab. 2.: Chemical composition of the ingot, in respect of gas- and carbon-content

Element	Ingot No. 1				Ingot No. 2				Ingot No. 3				Ingot No. 4				ASTM-Specification for Titanium Grade 1
	Electrode	B	M	T	Electrode	B	M	T	Electrode	B	M	T	Electrode	B	M	T	
C (ppm)	80-150	50	60	60	60-100	100	60	60	80-90	80		60	80	70	70	70	max. 1000
O (ppm)	600-900	700	650	600	700-1300	1300	1050	800	500-1300	1200		900	900	700	600	600	max. 1800
N (ppm)	100-150	180	170	170	80-160	180	170	140	70-160	140		160	120	100	100	100	max. 300
H (ppm)	76-94	25	24	24	34-42	35	30	26	36-41	28		27	24	18	12	15	max. 150
F (ppm)	-	60	60	60	-	60	60	60	-	-		-	-	-	-	-	

Common ESR slags are based on CaF_2, CaO and Al_2O_3, sometimes with additions of MgO and/or SiO_2 depending on the alloy grade to be remelted. For titanium remelting, slags containing Al_2O_3, CaO, MgO and SiO_2 cannot be used, as they are sources of undesired contaminations in titanium. According to the published literature, the most suitable slag for titanium remelting is pure calcium fluoride. The present work was, therefore, started with technically pure CaF_2.

Tab. 1 shows the remelting parameters of the three experiments.

		Melt No. 1	Melt No. 2	Melt No. 3	Melt No. 4
Electrode diameter	mm	110	110	110	110
Electrode length	mm	850	1000	1000	800
Electrode weight	kg	25,8	29,8	29,8	34,0
Mold diameter	mm	170	170	170	170
Current	kA	4	3,8	3,8	3,8
Power	kW	135	100	100	115
Melt rate	kg/h	19,0	52,6	54,2	40,7

Before starting the remelting process, the furnace chamber was evacuated to a pressure of approx. 2 x 10^{-2} mbar and subsequently backfilled with argon of a purity of 99,99 % to a pressure of approx. 1000 mbar. The first melt was carried out with pure CaF_2, whereas in the other melts some additions were made to the CaF_2 slag. It is evident from Table 1 that the melt rate of the first melt is much slower despite much higher power consumption.

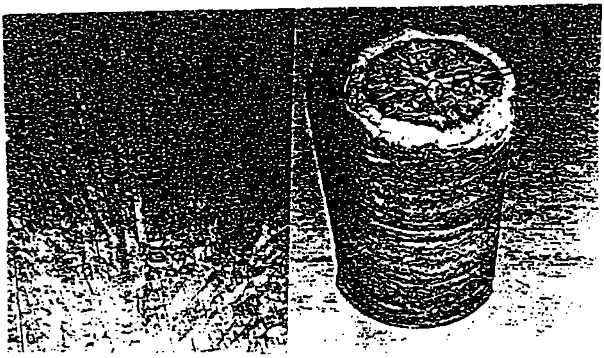


Fig. 7: Titanium Ingot and Primary Structure of the Ingot

Fig. 7 shows the titanium-ingot and the primary structure of the ingot. The macrostructure is dense and free from any oxides. The chemical composition of the ingots, with respect to gas and carbon contents, is listed in Table 2.

Production Route for Titanium

- Consumable Vacuum Arc Remelting at least Twice
- Forging to Slab or Square
- Surface Conditioning
- Rolling to Desired Dimensions

Fig. 5: Production Route for Titanium Sheet

As vacuum arc remelting can only produce round ingots, a forging sequence with subsequent surface conditioning must be introduced into the production route in order to get rollable material. Appreciable cost savings are, therefore, only possible by direct remelting to slabs or squares with subsequent rolling without any forging. This can be realized with electroslag remelting (ESR) of titanium.

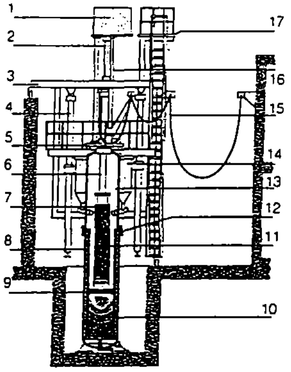
Electroslag Remelting of Titanium

Consolidation of titanium sponge by the ESR process was started in the early 1960's, especially in the former USSR /2/ but also in the USA /3/. It has been reported, that the former USSR is melting titanium with the ESR process on a production scale. In the Western World this technology has not experienced a technological breakthrough until now. LEYBOLD DURFERRIT GmbH has carried out tests in order to determine the metallurgical parameters required to achieve optimum results with respect to ingot quality.

Titanium is a reactive metal with high affinity for oxygen and nitrogen. Apart from that, titanium reacts with almost all oxides at high temperature. Bearing this in mind, the electroslag remelting of titanium must fulfill the following parameters:

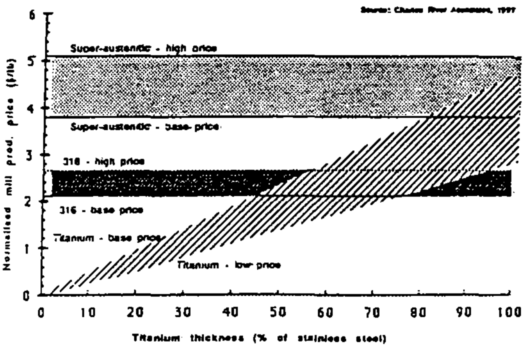
- furnace atmosphere must be free from oxygen and nitrogen, eg. an inertgas atmosphere must be secured
- slag must be free from oxides, which can be reduced by titanium

In order to assure a 100 % inertgas furnace atmosphere the usual ESR-furnace with a hood is not suitable. The ESR-unit must be a closed chamber installation. The conception of such an ESR-plant is not new. LEYBOLD DURFERRIT GmbH has already built such furnaces for electroslag remelting under pressure (PESR). Fig. 6 shows schematically a PESR-furnace, which can work also under vacuum or inertgas atmosphere. The present experimental work was carried out with such a laboratory scale PESR-furnace equiped with a pumping set for prior evacuation of the furnace chamber.



1 Electrode feed drive system.
2 Ball screw.
3 Movable furnace support frame.
4 Furnace lifting system.
5 Load cell system.
6 Electrode ram.
7 Electrode.
8 Water jacket.
9 Slag pool.
10 Ingot.
11 Mold assembly.
12 Quick flange.
13 Vacuum-/pressure chamber.
14 Alloy feeder.
15 Coaxial power cables.
16 Ram guiding system.
17 Maintenance platform.

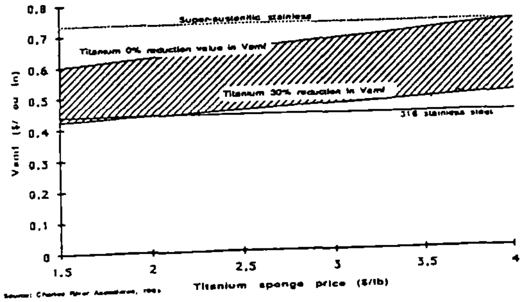
Fig. 6: Pressure/VAC-ESR Installation



Source: Charles River Associates, 1991

Fig. 3: Cost Effectiveness of Titanium Compared with Stainless Steels as a Function of Thickness

For effectively competing with stainless steel grade 316 it will be necessary to reduce the cost of the complete route of fabrication (Fig. 4).



Source: Charles River Associates, 1991

Fig. 4: Combinations of Sponge Price and Reduction in Mill Product (VAMF) can make Titanium cost effective with Super-Austenitic and 316 Stainless Steels

Fig. 4 demonstrates titanium in competition with super-austenitic stainless steel as well as with 316 stainless steel grade. It is evident that with a 30 % reduction in the cost of melting and further fabrication (VAMF = value added for melting and primary fabrication) with a simultaneous reduction of the sponge price, the cost of titanium comes very close to that of Grade 316 stainless. The question is how to lower the cost of melting and further fabrication. The present production route for titanium sheet products is as follows (Fig. 5):

- consumable vacuum arc remelting, at least twice
- forging to slab or square
- surface conditioning
- rolling

Non-Aerospace Applications of Titanium

Titanium has an excellent resistance to corrosion in most environments. Accordingly, a number of materials being used today in such applications can be totally or partly replaced by titanium. A recent study carried out by Charles River Associates /1/ shows a variety of materials against which titanium has a relative advantage (Fig. 1):

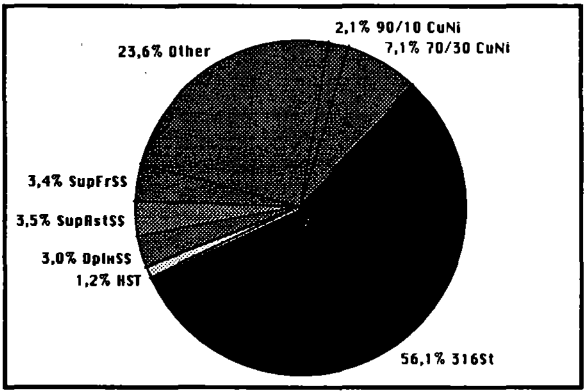
- Cupronickels (90/10 and 70/30)
- 316 stainless steel
- Super-ferritic stainless steel
- Super-austenitic stainless steel
- Duplex stainless steel
- Hastelloy C-276

Competing Material with Titanium

- Cupronickels (90/10 and 70/30)
- Super-Ferritic Stainless
- Super-Austenitic Stainless
- Duplex Stainless
- AISI 316 Stainless
- Hastalloy C-276

Fig. 1: Material Competing with Titanium

Fig. 2 shows the portion of the market of competing materials which can be potentially replaced by titanium. It is evident that titanium can gain a sizable market just by replacing the stainless steel grades in non-aerospace applications.



Source: Charles River Associates, 1991

Fig. 2: Weight Percent of Materials in Uses Potentially Available for Titanium Substitution

Fig. 3 shows that titanium may compete with high performance stainless steel at lower sponge prices and by reducing the thickness or by a combination of both. In the case of standard stainless steel grade 316, a substantial reduction of thickness is required. In this figure, only the cost for titanium sponge has been considered. Another important factor determining the titanium price is the cost of melting and fabrication of the final product.