Electroslag Remelting of Titanium

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Introduction

The titanium metal as an engineering material came into use in the 1950's in the USA in response to the critical demands far low density, high strength material for aircrafts and emerging space technologies.
The titanium-industry was mostly interested in the aircraft, specially military aircraft, and space market, where the cost was not a primary criterium for the selection of the material. But times have changed now.
The consumption of titanium in the aircraft- and space industry is stagnant for the last five years.
The titanium-industry must look for markets others than the aerospace industry.

Non-Aerospace Application of Titanium

Titanium has an excellent resistance to corrosion in most environments. Accordingly there is a number of materials being used today in such applications can be totally or partly replaced by titanium. In a recent study carried out by Charles River Associates /1/ in 1991 shows a variety of materials where titanium has a relative advantage (Fig. 1):

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

Fig. 2 shows the portion of the market of competitive materials which can be potentially substituted by titanium. It is evident, that titanium can gain a sizable market just by replacing the stainless steel grades in non-aerospace applications. Fig. 3 shows that titanium may compete with high performance stainless steel by reducing sponge prices and by reducing the thickness or by a combination of both. In 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. But another important factor for titanium price is also the melting and fabrication of the final product.

For an effective competition with the stainless steel grade 316 it will be necessary to reduce the cost of the complete route of fabrication (Fig. 4). The figure demonstrates the titanium competition with super-austenitic stainless steel as well as with 316 stainless steel grade. It is evident that a 30 % reduction of cost far melting and further fabrication (value added far melting and primary fabrication) with simultaneous reduction of sponge price the cost effectiveness of titanium comes very close to the grade 316 stainless. The question is, how to save cost in melting and further fabrication? The present production route for titanium rolled products is as follows (Fig. 5):

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

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

Electroslag Remelting of Titanium

Consolidation of titanium sponge by ESR-process was started early in the 1960's, specially in the USSR /2/ and also in the USA /3/. It is reported, that USSR is melting titanium with ESR-process in a production scale. But in the western world this technology did not experience a technological break-through till now. LEYBOLD DURFERRIT GmbH has therefore carried out experimental works in order to determine the suitable metallurgical parameters to get optimum results in respect of 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 equipped with a pumping set fpr prior evacuation of the furnace chamber.

The common ESR-slags are based on CaF_2, Al_2O_3 and CaO, sometime with some 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 can not 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 carried out therefore with technically pure CaF_2.

Tab. 1 shows the remelting parameters of the three experiments. Before starting the remelting process the furnace chamber was evacuated to a pressure of approx. $2x10^{-2}$ mbar and subsequently filled 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 two other melts some additions were made in the CaF_2-slag. It is evident from Tab. 1, that the melt rate of the first melt is much lower inspite of higher power consumption. 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 ingot, in respect of gas- and carbon-content, is listed in Tab. 2. It can be seen from Tab. 2, that there is an overall-decrease in the concentration of carbon and hydrogen in the remelted ingot. In 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 of course be mentioned, that the content of oxygen and nitrogen in the electrodes are probably not representative far whole electrode. It is evident, that all values are within the ASTM-specification for grade 1 titanium.

Conclusion

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

Literature

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/3/ C.E. Armentront and R.H. Nafziger
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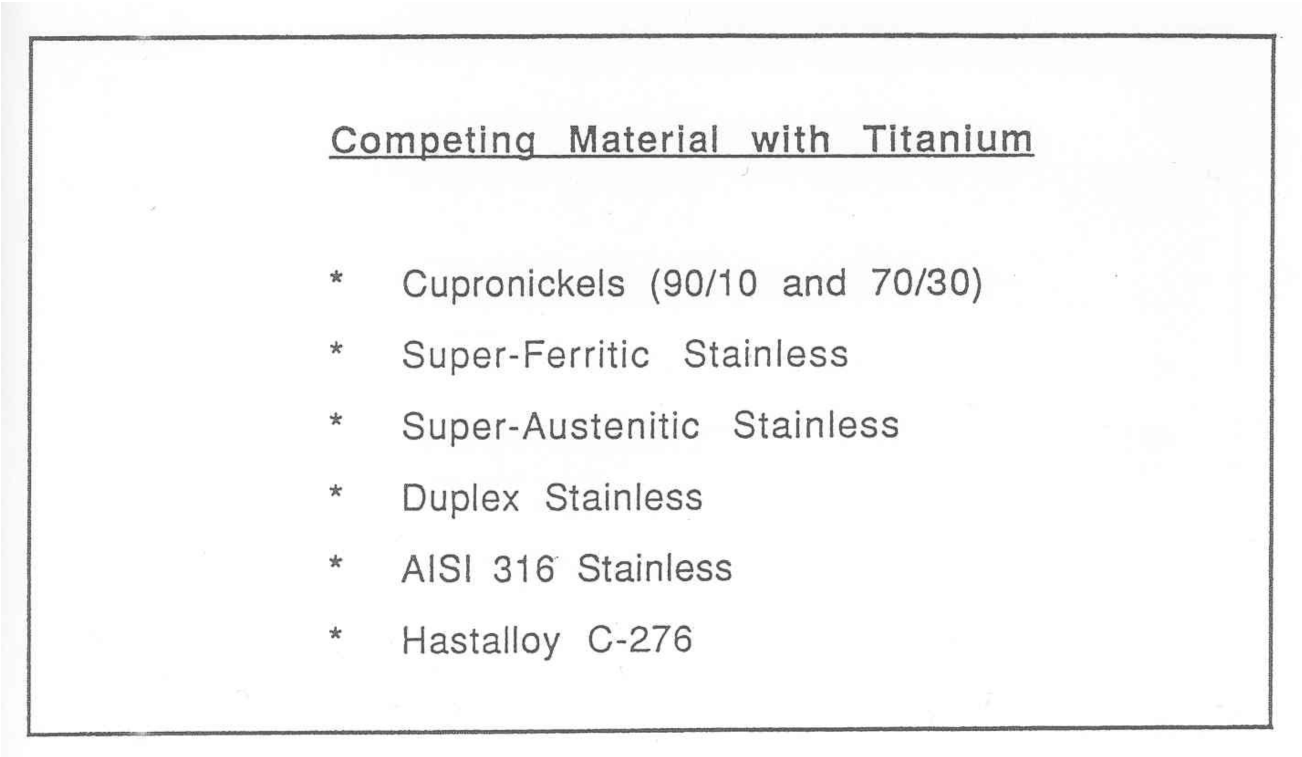

Fig. 1: Competing Material with Titanium

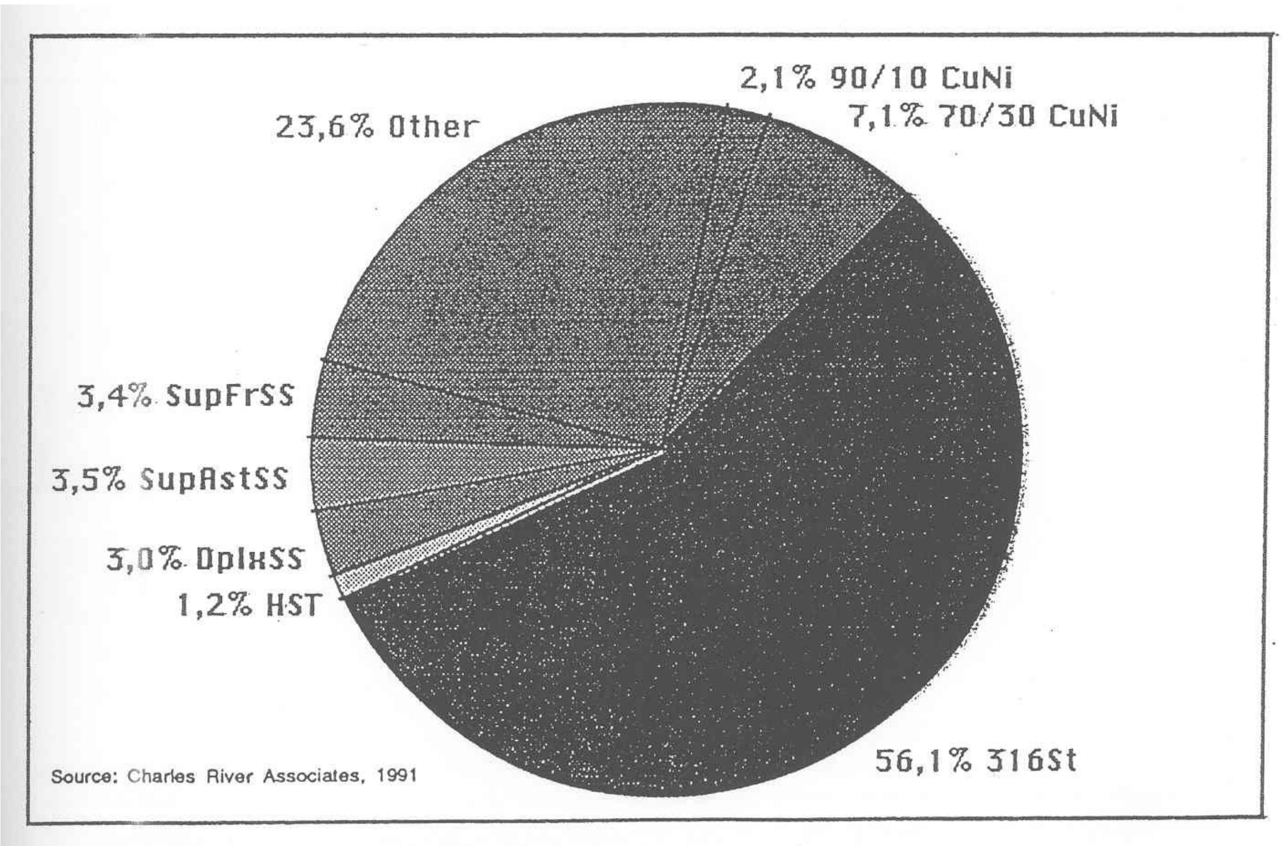

Fig. 2: Weight of Materials in Uses Potentially Available to Titanium

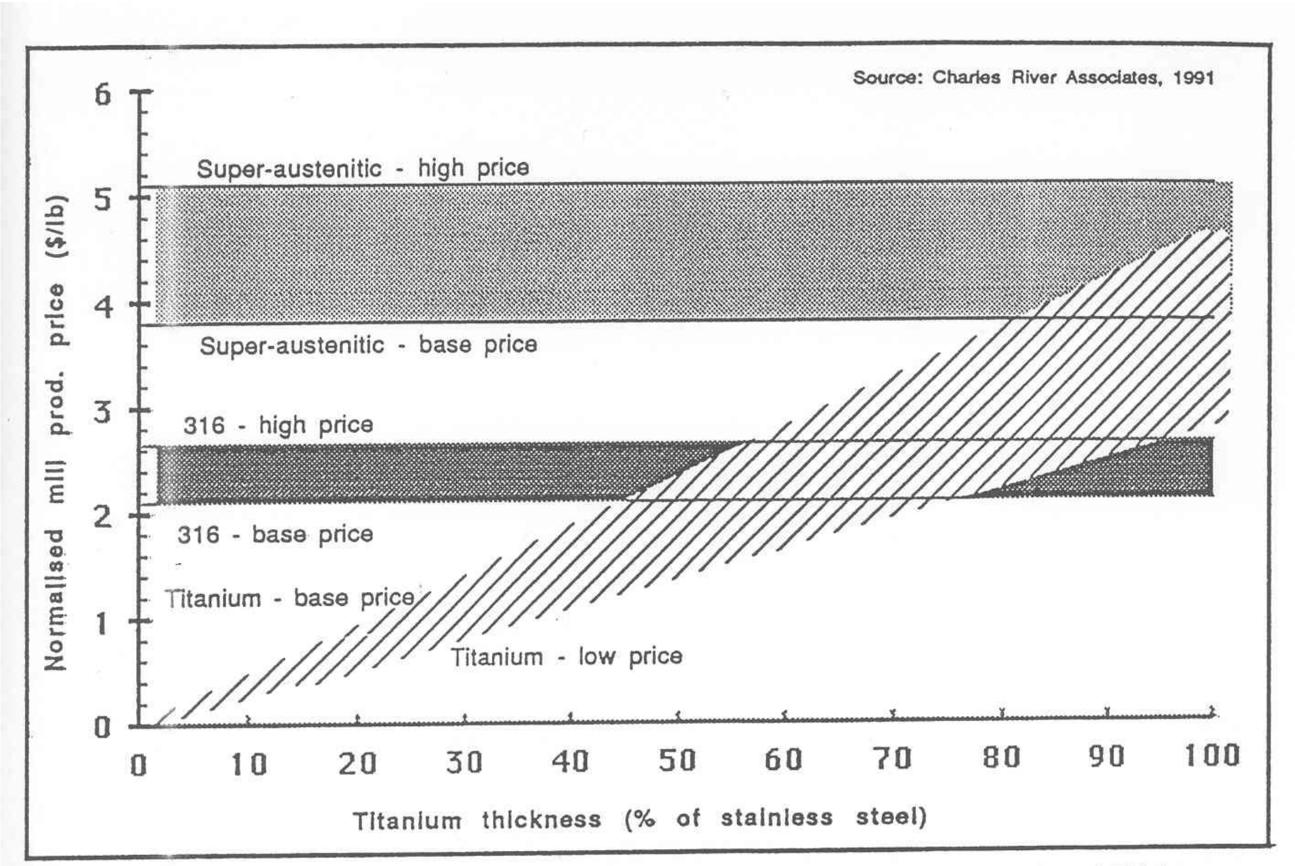

Fig. 3: Cost Effectiveness of Titanium Compared with Stainless Steels as a Function of Thickness

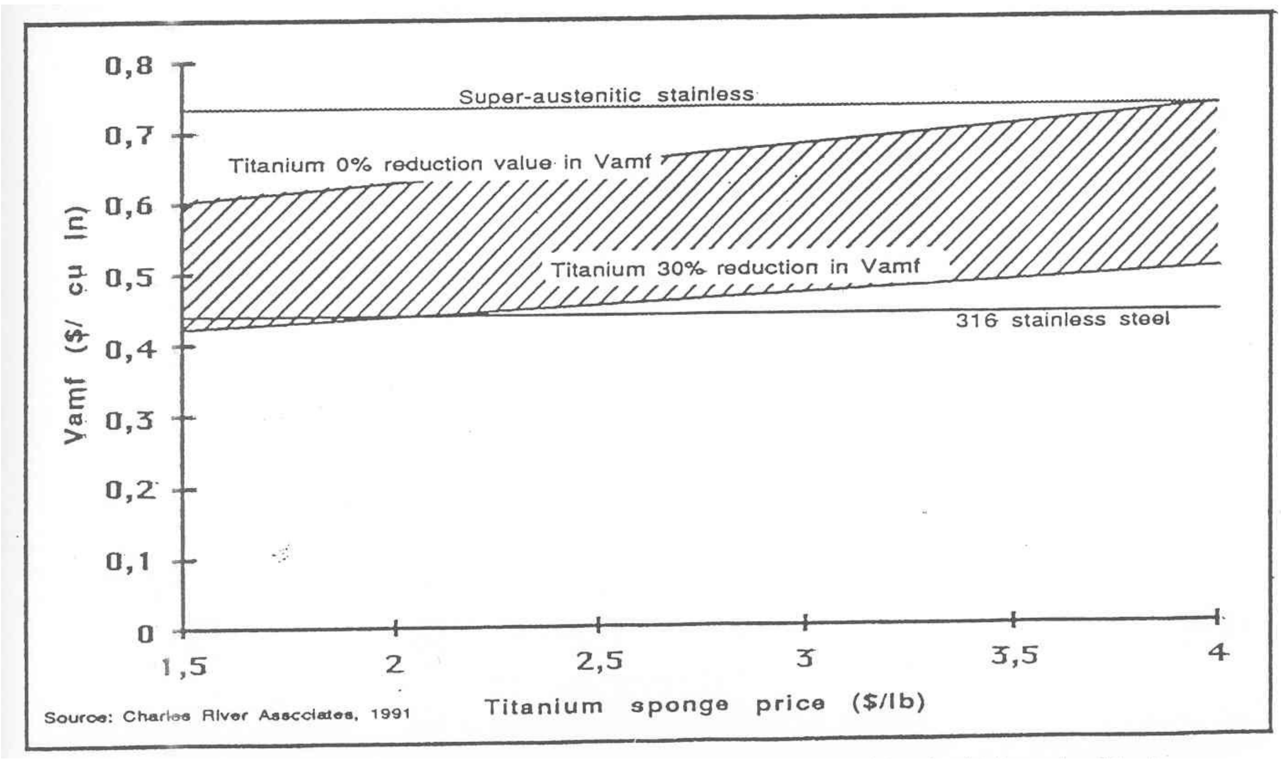

Fig. 4: combinations of Sponge Cost and Reduction in Mill Product Vamf which make Titanium Cost Effective with Super-Austenitic and 316 Stainless

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

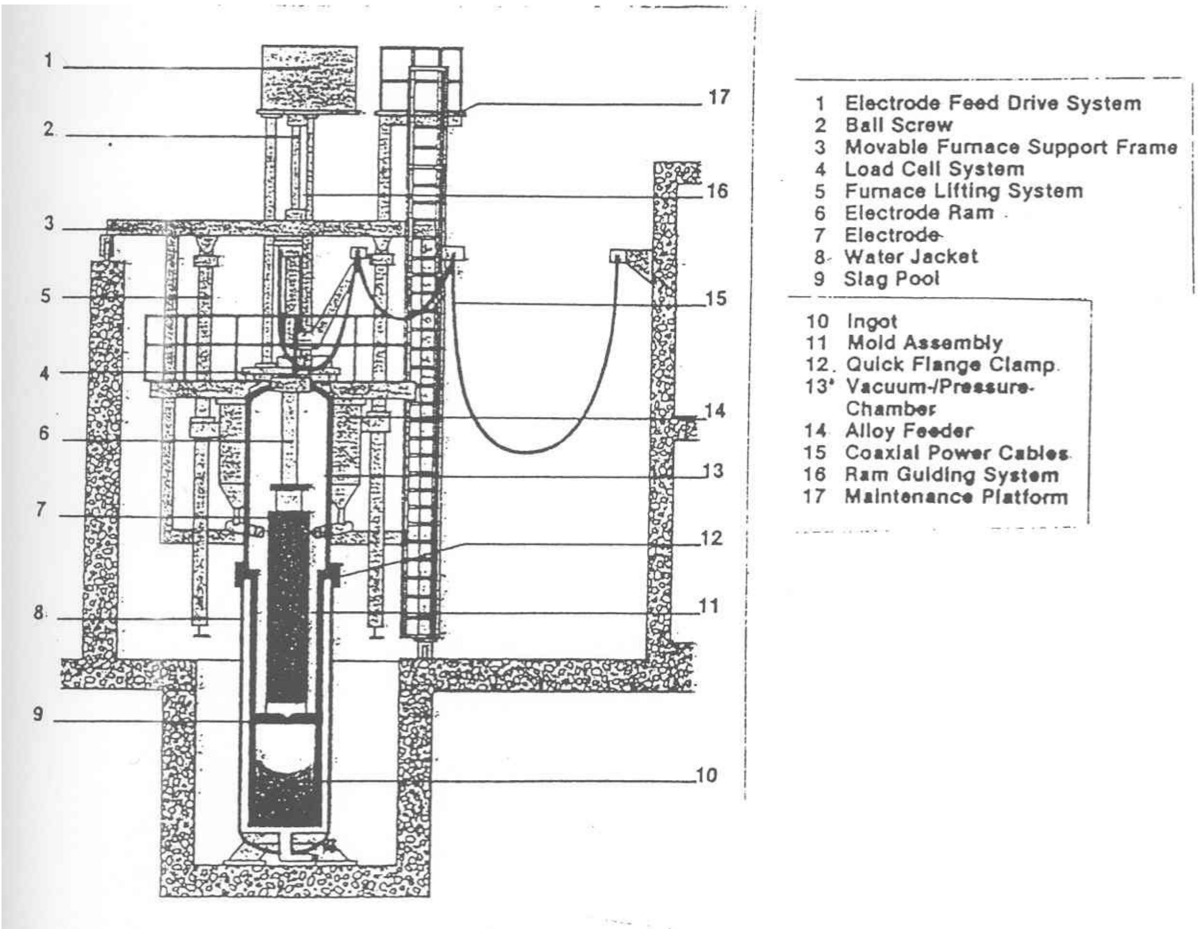

Fig. 6: Pressure/VAC-ESR Installation

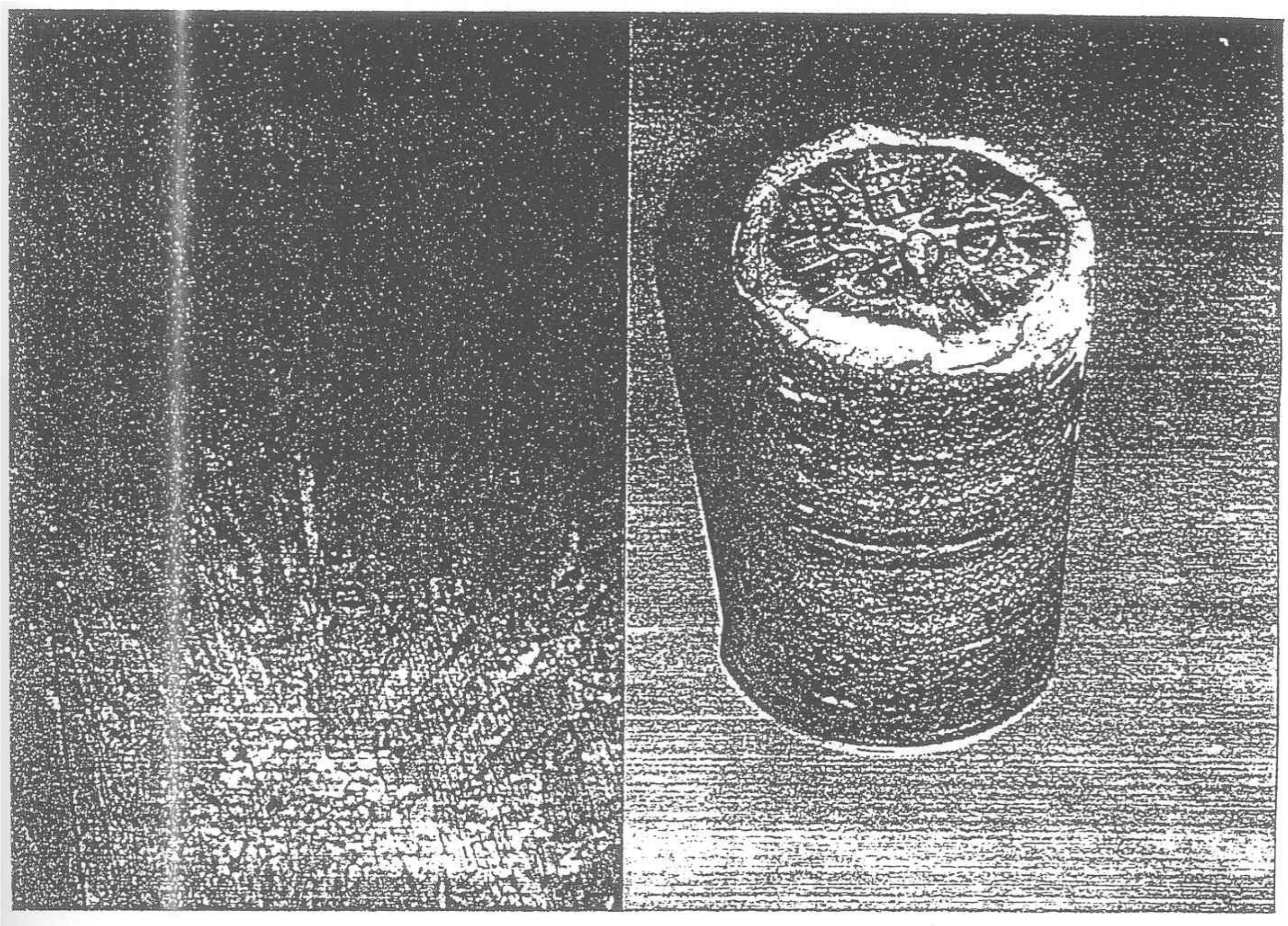

Fig. 7: Titanium Ingot and Primary Structure of the Ingot

Tab. 1: Remelting Parameters

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

Tab. 2: Carbon- and Gas-content of the Titanium Ingot

Element	Ingot No. 1				Ingot No. 2				Ingot No. 3				ASTM-Specification for Titanium Grade 1
	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				max. 1000
O (ppm)	600-900	700	650	600	700-1300	1300	1050	800	500-1300				max. 1800
N (ppm)	100-150	180	170	170	80-160	180	170	140	70-160				max. 300
H (ppm)	76-94	25	24	24	34-42	35	30	26	36-41				max. 150
F (ppm)	-	60	60	60	-	60	60	60	-				