

COLD CRUCIBLE INDUCTION MELTING OF TITANIUM

P. PAILLÈRE, J.-F. WADIER, Y. BOUSSANT-ROUX* and M. GARNIER*

CEZUS, Centre de recherches, F-73400 Ugine, France

*GIS-MADYLAM, Saint Martin d'Hères, France

INTRODUCTION

Induction melting is a process which is difficult to apply to reactive materials, either with a high melting point or of high purity, since reaction between the liquid metal and the refractory crucible lining (oxide ceramic or graphite) leads to pollution of the bath. This is particularly true for titanium, which melts at 1660°C and has a marked affinity for oxygen and carbon.

However, titanium and its alloys can be melted cleanly by cold crucible induction melting, which is an original variant of this technique. In this process, the furnace comprises a cooled copper crucible, made up of a number of separate segments to promote electromagnetic coupling with the metallic charge. In the case of titanium, two particular applications have been developed by the U.S. Bureau of Mines [1].

In the first of these, designated "Inductoslag Ingot Melting", titanium turnings can be melted, with the continuous production of billet (diameter 125 mm, length 1125 mm), while the second process, called "Inductoslag Casting" enables a titanium charge (>3 kg) to be melted prior to casting. The particular feature of these two processes is the use of a CaF₂ slag which isolates the liquid metal from the crucible.

For several years, CEZUS, in collaboration with the CNRS MADYLAM laboratory, has experimented with a new type of cold crucible induction furnace for the continuous casting of titanium and the refractory metals. This process called C.C.C.C (cold crucible continuous casting) involves :

- continuous melting of the divided charge materials or an consumable electrode.
- solidification of the liquid metal,
- continuous extraction of the solidified billet.

The system is designed to operate without slag, a significant improvement compared to the "Inductoslag Ingot Melting" process, since it avoids numerous difficulties, such as slag supply to the crucible, volatilisation, furnace cleaning constraints, billet peeling requirements, etc.

The second point is that device allows to reach very high temperatures and for example, Ti, Zr, Nb and even Mo have been successfully melted.

EXPERIMENTAL INSTALLATION

The furnace shown schematically in figure 1 comprises :

- a cooled double-walled stainless steel vessel,
- a charging system consisting of a stainless steel hopper, vibrators and a chute,
- a water-cooled segmented copper crucible,
- a cooled inductor,
- a mechanical billet extraction system.

The inductor is supplied by a medium frequency static generator. A pump unit enables a vacuum to be established in the furnace, and if required, it is possible to introduce an inert gas.

MELTING OF TITANIUM TURNINGS

The cold crucible induction furnace has been used to melt titanium and titanium alloy turnings. The melting procedure is as follows.

- The hopper is filled with turnings.
- A titanium primer with a diameter slightly smaller than that of the crucible is installed to contain the initial liquid.
- The furnace and hopper are pumped down to 10⁻² torr and then filled with argon.

- The operating frequency is set by selecting the value of the adjustment capacitor in accordance with the inductor characteristics.
- When the impedance has been adapted, the power is gradually transmitted to the charge until it melts, with the formation of a dome. The power is then adjusted to maintain a fluid bath and to control the height of the dome.
- The supply of turnings and the simultaneous continuous extraction of the billet can then be started.
- Melting is stopped when the desired length of billet is attained.

OPERATING PARAMETERS

It is important that a suitable operating frequency be selected for the melting process to proceed in a satisfactory manner. In fact, the choice depends on the effects required, since there are three coexisting frequency dependent phenomena :

- a thermal effect (maximum energy dissipation in the charge),
- a pressure effect, which determines the form of the free surface of the liquid metal,
- a stirring effect in the metal bath.

Each of these phenomena can be favoured at the expense of the others by adjusting the frequency. An optimum frequency can be shown to exist for each of the effects, and the three values are quite distinct.

The effect of frequency f is described by the dimensionless "screen parameter" R_ω :

$$R_\omega = \mu_0 \sigma \omega R^2$$

where : μ_0 is the magnetic permeability of vacuum,
 σ is the electrical conductivity of the material at the melting temperature,
 ω is the frequency of the current in the inductor ($= 2\pi f$),
 and R is the radius of the crucible.

R_ω can be shown to have the following characteristic values :

- * 2 : establishment of a plane free surface
- * 25 : optimum value for heating
- * 40 : optimum value for stirring.

The power transmitted is a second important parameter. It should be sufficient to melt the turnings, but must not produce too high a dome. In effect, it can be shown theoretically, and has been experimentally verified, that the dome height H is proportional to the magnetic field, and therefore to the power transmitted, through the relation :

$$H = B^2/2 \mu_0 \rho g$$

where : B is the magnetic field strength inside the crucible,
 ρ is the density of the liquid metal,
 g is the acceleration due to gravity.

RESULTS

Billets of excellent surface quality are obtained when the frequency and transmitted power are optimised and stable with time. Figure 2 shows a 100 mm diameter billet obtained from TA6V turnings; the skin is smooth and crack-free. On the contrary, the cracked surface of a billet of the same alloy shown in figure 3 illustrates the effect of a poor choice of frequency.

Table 1 compares the chemical analysis obtained on TA6V billet with that of the initial turnings.

	Al (%)	V (%)	Fe (ppm)	Cu (ppm)	O (ppm)	N (ppm)	C (ppm)
Turnings	6.2	4.1	1500	<50	2200	130	250
Billet	6.2	4.0	1550	<50	2250	120	260

It can be seen that there is no increase in the oxygen and nitrogen contents, nor in that of copper, showing that the crucible has not been attacked. Furthermore, melting under argon prevents the loss of volatile elements such as aluminium.

As in any induction melting process, stirring is extremely vigorous. In consequence, in spite of the steep thermal gradients induced by the use of a cold crucible, fine equiaxed macrostructures can be obtained in alloys such as TA6V, figure 4. In general, the solidification structures produced by this process are found to be much finer than those obtained with the conventional consumable electrode arc melting technique.

CONCLUSIONS

The C.C.C.C. (cold crucible continuous casting) is a new process for the induction melting of high melting point reactive materials. Continuous billet extraction can be carried out without the need for a slag, provided that the design is optimized and that the frequency and the transmitted power are adapted to suit the material to be melted.

By melting turnings, it has been shown in the case of titanium and its alloys that sound billets can be obtained with a good surface quality, a fine solidification structure and a good control of the chemistry.

The CEZUS plant enables the production of 150 mm diameter and several meters length billets suitable for direct extrusion or rolling.

ACKNOWLEDGMENTS :

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REFERENCES

[1] P.G. CLITES, U.S. Bureau of Mines. (1982), Bulletin 673.

FIGURE 1

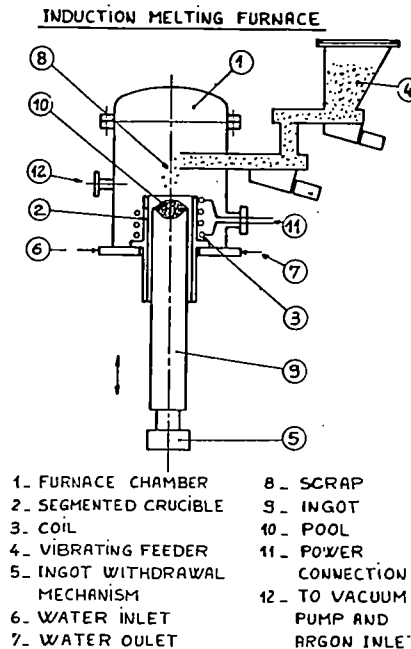


Figure 2

TA6V BILLET OBTAINED WITH THE C.C.C.C. PROCESS

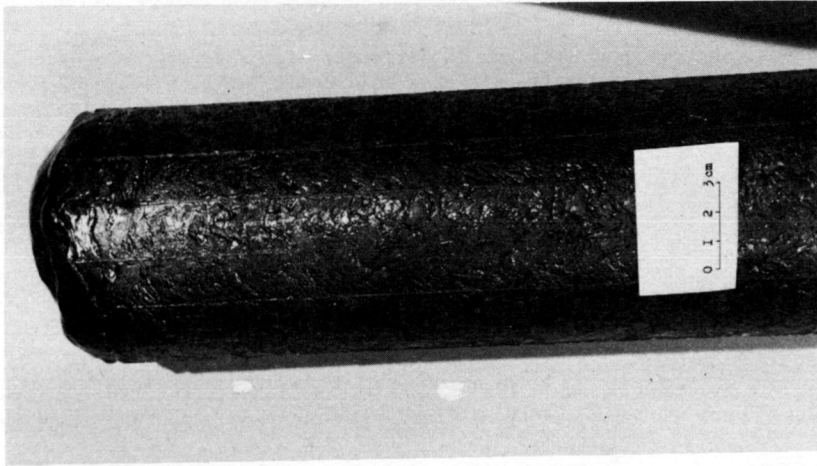


Figure 3

CRACKED TA6V BILLET DUE TO A POOR CHOICE OF FREQUENCY

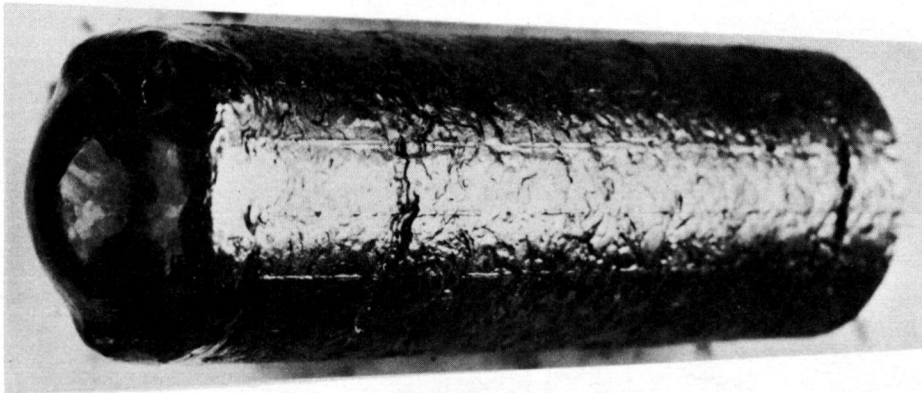


Figure 4

MACROSTRUCTURE OF A TA6V BILLET OBTAINED BY THE C.C.C.C. PROCESS

