PRODUCTION TITANIUM PLASMA COLD HEARTH MELTING

W.R. Chinnis *W.H. Buttrill*
Teledyne Allvac *G.E. Aircraft Engines*

ABSTRACT

Cold hearth melting is a technique now being used for production of titanium alloys. This method provides elimination of harmful inclusions that occasionally occur with conventional melting techniques. Several production titanium cold hearth furnaces are now operating, including a plasma cold hearth furnace at Teledyne Allvac. Defect seeding experiments have proven this furnace's capability to remove the two types of inclusions found in titanium alloys . Evaluation of plasma cold hearth plus single VAR has demonstrated chemical uniformity, structure, and mechanical properties equivalent to conventionally produced material. Control of as-plasma melted hydrogen content has been achieved with catalytic oxidation of hydrogen in the recycled gas stream. An Air Force sponsored program is presently investigating cold hearth single melt titanium for premium grade applications.

INTRODUCTION

A significant problem of titanium alloys used in critical applications is the occasional occurrence of high density and hard alpha inclusions. Catastrophic jet engine failures have been directly attributed to the undetected presence of such defects in titanium components. Cold hearth melting is a technique designed to produce the highest quality titanium alloys free of these inclusions. A process consisting of cold hearth melting plus single vacuum arc remelting (VAR) is quickly gaining acceptance as superior to conventional double or triple VAR. In addition, an Air Force sponsored program is presently evaluating a cold hearth single melt process for premium quality titanium.

Cold hearth furnaces use either electron beam guns or plasma torches as the heat source. At least four producers are now cold hearth melting titanium alloys at various qualification stages. One of these producers, Teledyne

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An essential reason for the permanent temperature variation in the electrode tip is probably the turbulent molten pool surface, which changes continuously when raw materials are charged. If the charged material is melted down and dissolved completely and the feeding of raw materials is interrupted, the measured temperatures in the electrode tip will be much more uniform even if the eletrode moves.

On condition that the local course of temperature is quasi-stationary the temperature of the copper tip at its inner water-cooled surface make infer an amount of 70 to 90 °C by lineary extra-polation. The outer surface reaches 500, 560 and 640 °C at melting currents of 10, 14 and 16 kA. A further increase of melting current exceeding 16 kA should be avoided in view of the service life of the copper tip of the electrode.

Electrode cooling. Safe and effective cooling is important for a favourable service life of the electrode tip. There have been established several design changes to optimize the stream of water and the heat- exchange at the tip. The buckling behaviour at the radiussed shape of the tip cannot be prevented completely. However, the internal water pressure can be slightly diminished and the stream of water can be increased.

Conclusion

The measured data show the correlation between electrical efficiency and heating stream as well as the influence of melting current on the temperature gradient in the tip of non-consumable electrode under different conditions.

Temperature measurements in the electrode tip show a higher thermal strain of the electrode tip with the increasing melting current. The temperature of the outer surface reaches 640 °C when raising the melting current up to 16 kA. A further improved water cooling of the internal wall decreases its temperature only by 10 to 20 °C, which is nearly equal to the reduction of its outside temperature. A thinner wall of the tip could be more effective if its stability and service life remained unchanged.

References

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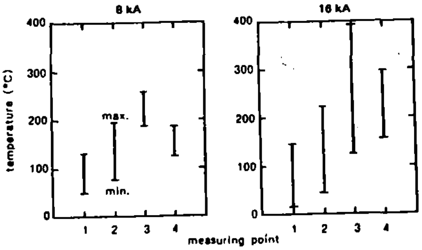
It clearly shows the dependence of the course of temperature upon the electrode distance from the molten pool. If the arc is interrupted and the electrode pulls back, the wall temperature of the electrode tip will cool quickly by about 40 °C. The rotation of the electrode doesn't induce a cyclic temperature variation as supposed. It is impossible to establish such an effect even by more stretching the recording, not even for the smallest possible distance of 3 mm between the measuring point and the tip surface.

The courses of temperature of measuring point 1 and 2 are similar to the measuring point 3, only the amplitudes are diminished. All test results of measuring point 4 are remarkable because of their reflected image to all other points. There are grounds for the assumption that this is caused by the wandering of the arc from the inner side to the outside of the pad of the electrode tip.

Influence of electrode position and melting amperage. Independent of measuring point and melting amperage there is a scattering of the various tip wall temperatures, which increase with increasing amperages between 8 and 16 kA as shown in figure 9 for a time range between 5 and 10 min. It shows the high alternating temperature loading of the tip.

If the continous electrode rotation is stopped for a few seconds, the temperature in the electrode tip will remain nearly constant.

The angularly mounted electrode directed assymetricly to the crucible doesn't influence the temperature in the electrode. The thermal strain of the electrode tip is nearly constant over the whole molten pool surface independent of the crucible diameter between 500 and 750 mm.



Ti6Al4V, crucible dia 630 mm

distance from the surface:
measuring point 1 : 9,2 mm
2 : 12,0 mm
3 : 6,2 mm
4 : 9,2 mm

Figure 9: Influence of melting current on the wall temperature of the electrode tip

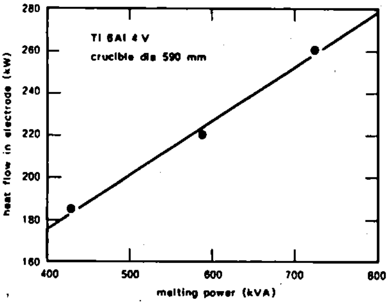


Figure 7: Heat flow in the electrode in as influenced by the melting power

Occurrences in the electrode tip.
The electrode tip is mechanically and thermal highly charged by the mostly unavoidable touching of the melting material which creates an attack of the tip surface. Even more destructive is the distortion of the electrode tip. It narrows the cooling water ducts, can cause cracks and limits its service life.

Temperature gradient.The measuring point 1 has been situated in the center of the tip, just below the inner water tube, where the cooling water streams out. The other measuring points, 2, 3 and 4, are situated in the area of the wandering source of the arc. Because of their short distance from the molten pool surface they are subjected to extreme conditions. The flow rate of cooling water in this area is very high and the temperature changes rapidly.

For getting a better recorded short time information the course of temperature and the position of the electrode have been expanded and limited to 4 min only as shown in Figure 8.

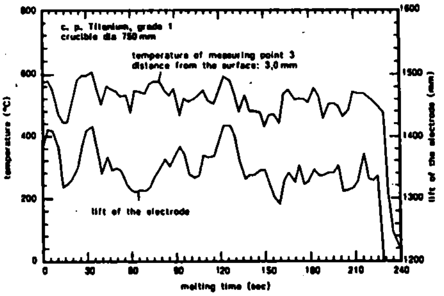


Figure 8: Course of wall temperature and lift of the electrode during melting time (measuring point 3)

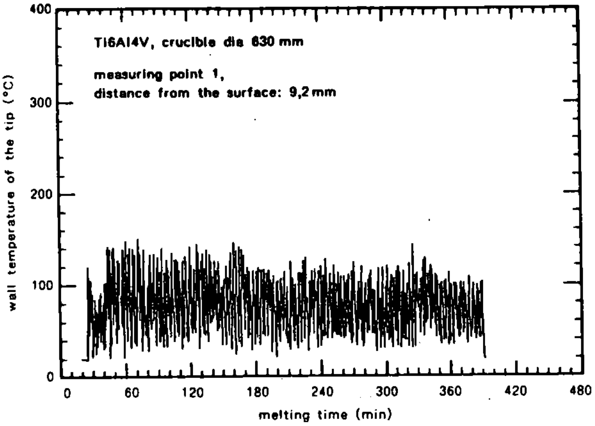


Figure 5: Wall temperature in electrode tip (measuring point 1)
during melting time

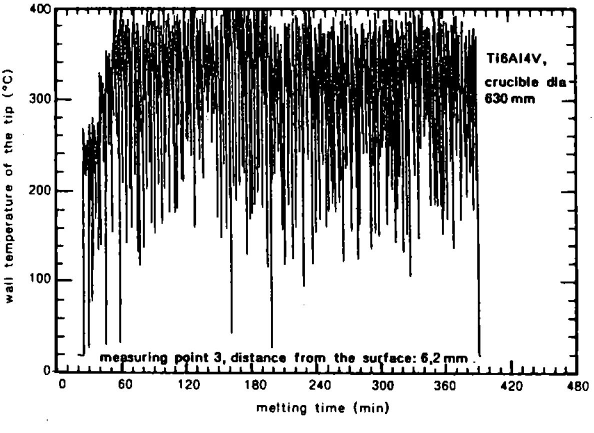


Figure 6: Wall temperature in the electrode tip (measuring point 3)
during melting time

Correlation of electrical power and heat flow.
The simultaneous data logging of melting current and voltage permits calculation of the electrical power directly as their product. Much of the electrical power is transformed into heat of which an indication is found in the temperature level of the cooling water of the electrode. A higher melting rate increases the heat charge of the electrode and also the heat flow, which is led away by the cooling water as shown in Figure 7.

The melting voltage is in a close correlation with the distance of the electrode from the molten pool surface. Figure 4 shows the superimposing influences of the permanent changing position of the electrode tip over the molten pool and the adapted distance to it which is automatically kept by the control system, operating in the voltage control mode.

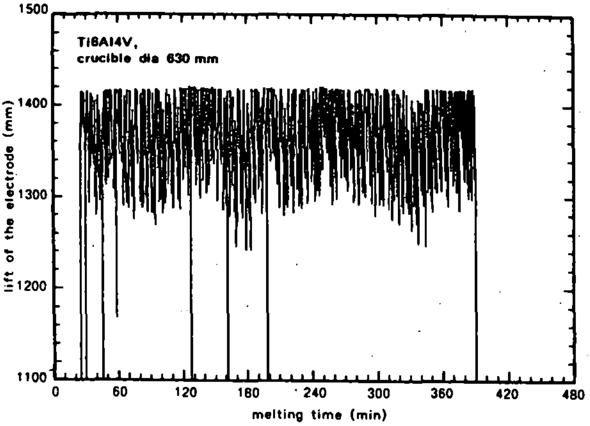


Figure 4: Lift of the electrode during melting time

The flow of cooling water in the electrode decreases about 1 % only during the melting-time and the temperature of the cooling water slightly varies. The temperature between incoming and outgoing cooling water of the electrode differs constantly at 4 °C.

The copper wall of the electrode tip however is much more influenced by variations of temperature. The absolute temperature depends very much on the distance of the measuring point from the tip surface as well as on its position within the tip. While the maximum value of the temperature in the tip center (Figure 1, measuring point 1) reaches 120 °C with a relative low spread (Figure 5), the temperature on top of the tip increases to 400 °C and even more (Figure 1, measuring point 3) with an extensive spread as shown in Figure 6.

When the melting starts and the amperage is increased step by step, the temperature in the tip rises, too. Short time interruption of melting current causes an immediate drop of the temperature in the electrode tip close to 20 °C.

Results and discussion

Time depending operation characteristics.

The melting current for a typical melt process during a melting time of about 6 h is shown in Figure 2.

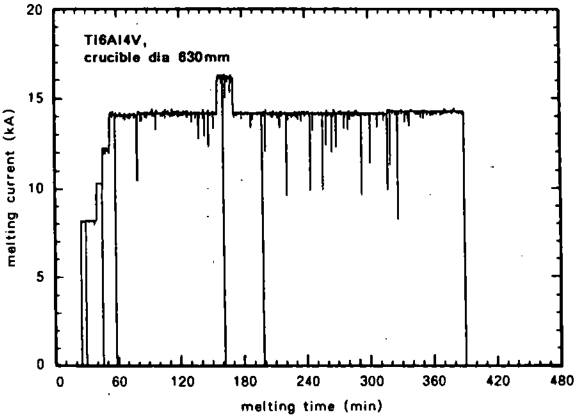


Figure 2: Melting current during melting time

At the beginning, the melting current is increased in several steps from 8 to 10, 12, 14 kA and after 2 h for a period of 15 min to 16 kA. Besides this, the diagram shows some interruptions of melting current only for some seconds, which mostly correspond to extremely high voltage fluxuations amplitudes as shown in Figure 3.

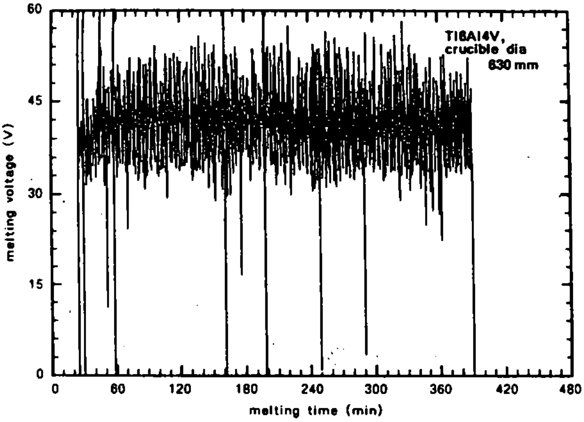


Figure 3: Melting voltage during melting time

Objective of this investigation is to determine the correlation between melting condition, energy exchange and temperature influence on the tip of the non-consumable electrode.

Experimental procedure

The temperature distribution in the wall of the copper tips of the electrode has been measured by mostly four thermocouples which were fit in different distances from the tip surface located as shown in Figure 1.

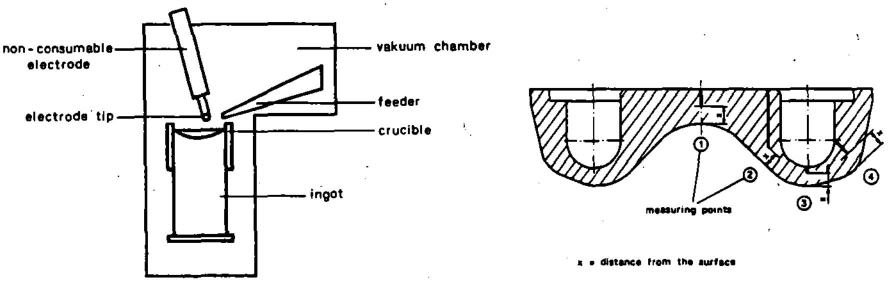


Figure 1: Schematical diagramm of the furnace and location of the measuring points in the electrode tip

The smallest possible distance between the single measuring point and the tip surface is 3 mm. The bundled thermocouple wires have been situated within the inner water tube over the whole length of the electrode up to a mercury collector, where the measured voltage is deducted from the rotating electrode. This allows an undisturbed measurement of the temperature in the electrode tip during the whole melting time.

All signals are recorded by a process computer. The cyclus of measuring is between 2 and 600 s, providing information about short time processes, like the influence of electrode revolution on time-temperature profiles at each of the electrode tip thermocouple locations.

Investigations have been carried out on heats of c.p. titanium and titanium alloys, mainly Ti6Al4V. The ingot diameter varies between 500 and 750 mm, the ingot weight between 3000 and 6000 kg. The raw materials consists of sponge, alloying additions and feedstock scrap including chips.