THE VACUUM ARC REMELTING OF LARGE DIAMETER ALLOY 706

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Abstract

INCONEL alloy 706® is a precipitation hardenable alloy that provides high mechanical strength in combination with good fabricability. It was developed more than 20 years ago from INCONEL alloy 718. The chemistry of this alloy allows the production of large, triple melted, high quality ingots. This paper describes the effects of VAR melt rate and electrode-to-crucible fill ratio on INCONEL alloy 706 ingot quality.

Introduction

In the recent past, the use of INCONEL alloy 706 in the application of land-based gas turbines has grown dramatically. This growth has been fueled primarily by ever increasing demands on the world's electrical power generation capability. In the United States for example, present electrical power demands are causing surplus power levels to be at their lowest since WWII(1).

The land-based gas turbine is an offspring of the jet aircraft engine, but much larger in size. Improved efficiency is obtained by operating at gas temperatures in excess of 2300°F. Because of these higher temperatures and more severe operating conditions, INCONEL alloy 706 has been chosen for several major components of these gas turbines due to its combination of high strength and toughness at both room and elevated temperatures as well as its metallurgical stability during long- term exposures to "in service conditions."

Presently, this alloy is being supplied via "triple melting," a process increasingly used for rotating parts in jet aircraft engines to meet stringent requirements of uniform ingot structure and low sulfur contents. The triple melt method includes VIM + ESR + VAR. The size of the industrial gas turbines being used has dictated that the product supplied for this application be produced in VAR ingot diameters ranging from 840 to 920mm with weights ranging from 6.8 to 16.8

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(1)"The 17% Solution," Financial World, James L. Srodes, September 18, 1990.

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tonnes. These size requirements, coupled with the segregation tendencies of all superalloys, have led to a good deal of work in the area of defining the VAR process capability for this product. Although much study has been done in all of the production steps for this product, most of the attention has been given to the VAR step, the last chance to solidify the ingot properly.

Historically, the VAR process has been evaluated extensively. However, most research has concentrated on smaller ingot sizes of alloys such as INCONEL alloy 718. Although the alloy and sizes differ, the same production concerns exist: 1) alloy segregation tendencies, 2) process capabilities, and 3) process optimization. The balance of this paper discusses some findings in these areas.

Discussion:

The VAR process, just as any production process, has critical parameters that need to be controlled in order to insure the regular production of a quality product. Various industry wide, VAR studies have looked at parameters such as electrode gap, furnace pressure, and operating amperage levels just to name a few. The work presented here looks at the effects of VAR electrode/crucible fill ratios and VAR steady state melt rates on the solidifying VAR ingot structure of large diameter INCONEL alloy 706. Although this type of work has been performed for all VAR ingot sizes of INCONEL alloy 706 presently produced, the information presented in this report deals entirely with the 840mm diameter VAR ingot size. The data used to gage the effects of these parameters included VAR ingot shelf thickness, VAR stability, VAR ingot pool depth, and VAR ingot macrostructure.

VAR Fill Ratio:

In order to evaluate the effects of different VAR annuli on the resulting VAR ingot structure, a full size VAR electrode of INCONEL alloy 706 was machined to different diameters along its length. The resulting VAR fill ratios ranged from the lowest (x) to the highest (1.54x). After VAR, the entire ingot was sampled in a manner that allowed the resulting macrostructures from each fill ratio condition to be inspected both longitudinally and transversely. From these etch slices, the VAR ingot shelf thickness was obtained. VAR ingot shelf is typically formed by the first molten metal to solidify nearest the VAR crucible. For this alloy and size, this shelf can be seen as a lighter etching area at the extreme outer diameter of the VAR ingot. VAR ingot shelf measurements for fill ratios up to 1.16x were easily obtained and are shown in Figure 1. Although VAR ingot shelf was observed at the higher fill ratios, it was not measurable due to its relative faintness. The higher fill ratios did have their problems, however. At fill ratios greater than or equal to 1.44x, extremely unstable, undesirable VAR conditions were observed. These instabilities were observed in the ram travel, arc voltage, amperage, melt rate and drip short frequency. It is believed these instabilities were caused by the electrode getting too close to the outer diameter of the solidifying VAR ingot and creating "dead short" conditions.

VAR Melt Rate:

In order to evaluate the effects of different VAR steady state melt rates on the resulting VAR ingot structure, a full size VAR electrode of INCONEL alloy 706 was VAR'ed at different steady state melt rates. The melt rates evaluated ranged from the lowest (z) to the highest (1.8z). After VAR, the resulting VAR ingot was sampled in a manner that allowed the region representing each steady state melt rate to be macroscopically evaluated both longitudinally and transversely.

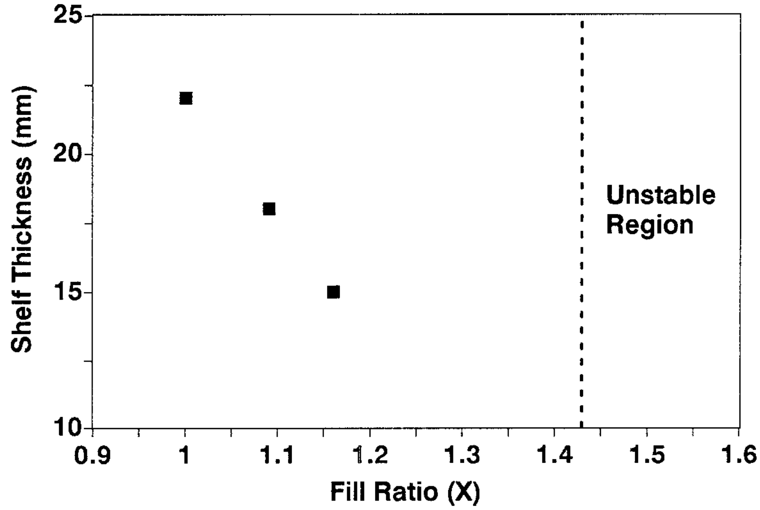

FIGURE 1

From the longitudinal samples, pool depth measurements were obtained for each steady state melt rate. This data is shown in Figure 2. Since these relative differences of VAR ingot pool depth represent relative differences in local solidification times (LST) and since longer LST's increase the formation tendencies of positive segregation, the fact that freckling was observed in the VAR ingot region representing the highest steady state melt rate of 1.8z was no surprise. These are shown in Figure 3.

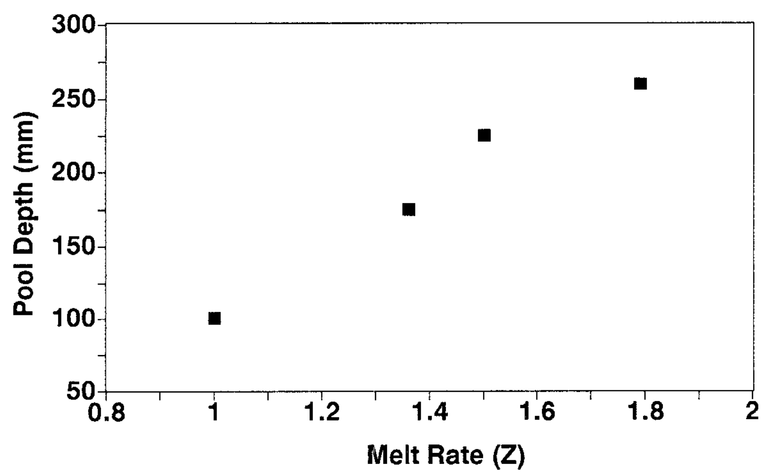

FIGURE 2

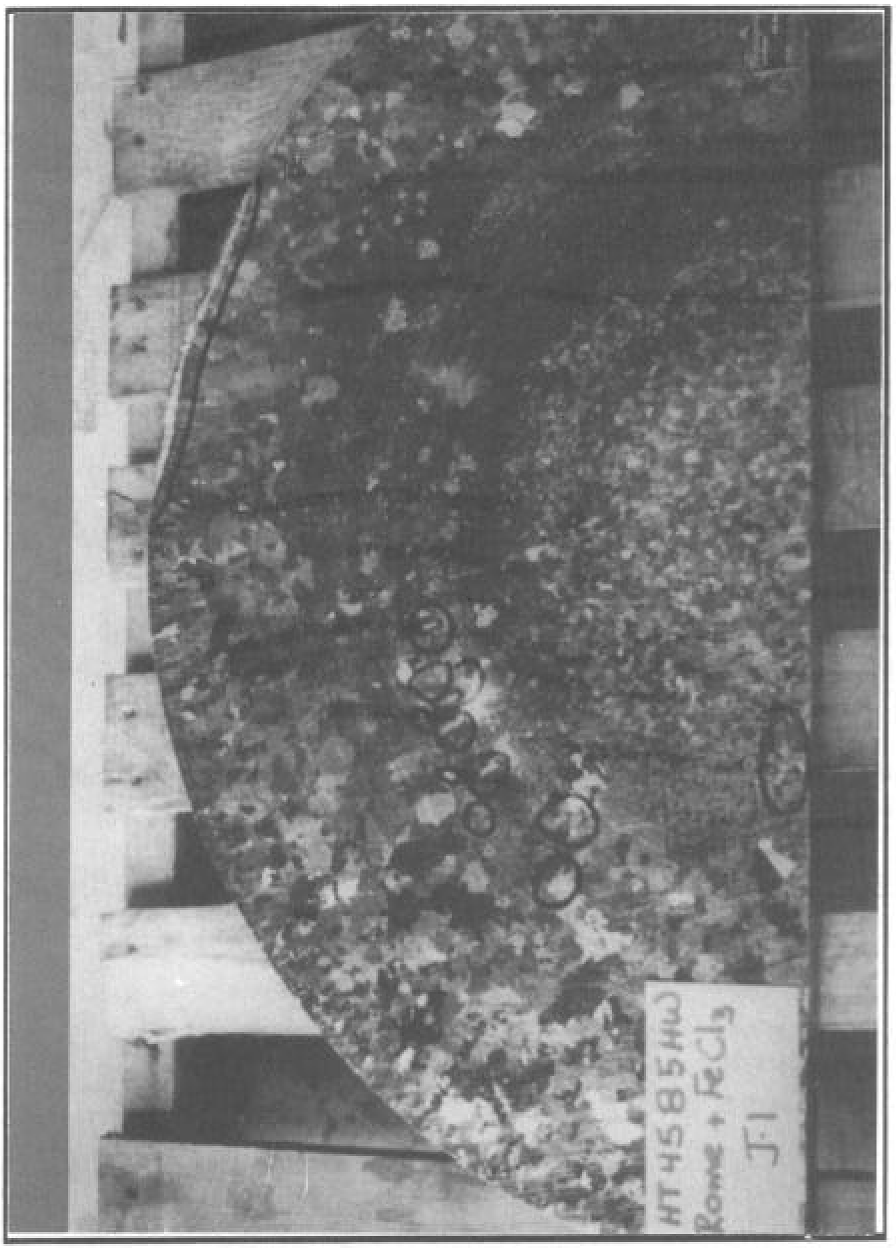

Figure 3. Freckles observed in 840 mm diameter VAR ingot of INCONEL alloy 706. Freckles identified with circles.

<u>Summary:</u>

A primary goal of this work was to more clearly define the window of operations for the consistent production of a quality VAR ingot product of large diameter INCONEL alloy 706. Although this paper does not define this window in absolute numbers, the work that was performed clearly provided this data. The VAR operating conditions to be avoided were rather obvious.

From the fill ratio data it can be seen that as the fill ratio decreases, the VAR ingot shelf thickness increases. Since VAR ingot shelf is thought to be a potential source for both discrete and dendritic white spots(2), lower fill ratios would not be considered optimal VAR operating conditions. Additionally, this increased VAR ingot shelf would require increased VAR ingot surface conditioning losses in order to remove it from the shipped product. Obviously this would result in decreased product yield. At the other extreme, due to the observed VAR operating instabilities, the higher fill ratios would not be considered optimal VAR operating conditions either.

From the melt rate date, once again, neither of the extreme VAR operating conditions would be considered optimal. The highest steady state melt rate is not optimal due to its obvious freckle forming tendencies. The negative effects of freckles on this product are catastrophic. The lowest steady state melt rate would not be considered optimal due to its lower productivity level.

Conclusions:

Although this paper does not specifically detail the process requirements for the production of large diameter VAR ingots of INCONEL alloy 706, it does show the negative effects of extreme VAR electrode/crucible fill ratios and extreme VAR steady state melt rates. The work that was performed, however, more than adequately showed what is needed to consistently produce a quality product for this application. This work not only assisted in defining operating limits for fill ratios and steady state melt rates, but also for other variables such as electrode straightness, electrode geometry, electrode plumbness, electrode gap and drip short frequency.

(2) "New Knowledge About White Spots in Superalloys," Advanced Materials and Processes; Lawrence A. Jackman, Gerrant E. Mauver, Sunil Widge; May 1993.