PRODUCTION OF ROLLED ALLOY 718 BILLET FROM VADER INGOT

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Abstract

VADER is a unique casting technology capable of producing a fine-grain ingot. VADER process development has concentrated primarily on high-strength superalloys, particularly P/M alloys, but it is also capable of producing materials such as Alloy 718. The structure and mechanical properties of rolled billet of Alloy 718 produced from 8 to 12-inch diameter VADER ingots is reported.

Introduction

Vacuum Arc Double Electrode Remelting (VADER) is a unique casting technology that is capable of producing a uniform, fine-grain ingot. VADER development has concentrated mostly on very high strength superalloys, including P/M alloys such as IN100, but it is also capable of producing more conventional alloys, such as Alloy 718. Development work is being conducted with Alloy 718 primarily because VAR billet is readily available for use in VADER.

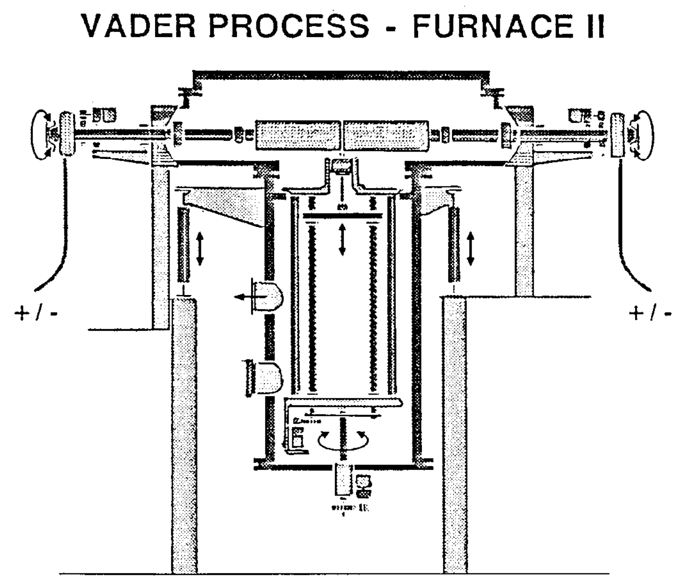

Figure 1. Schematic of VADER FURNACE II.

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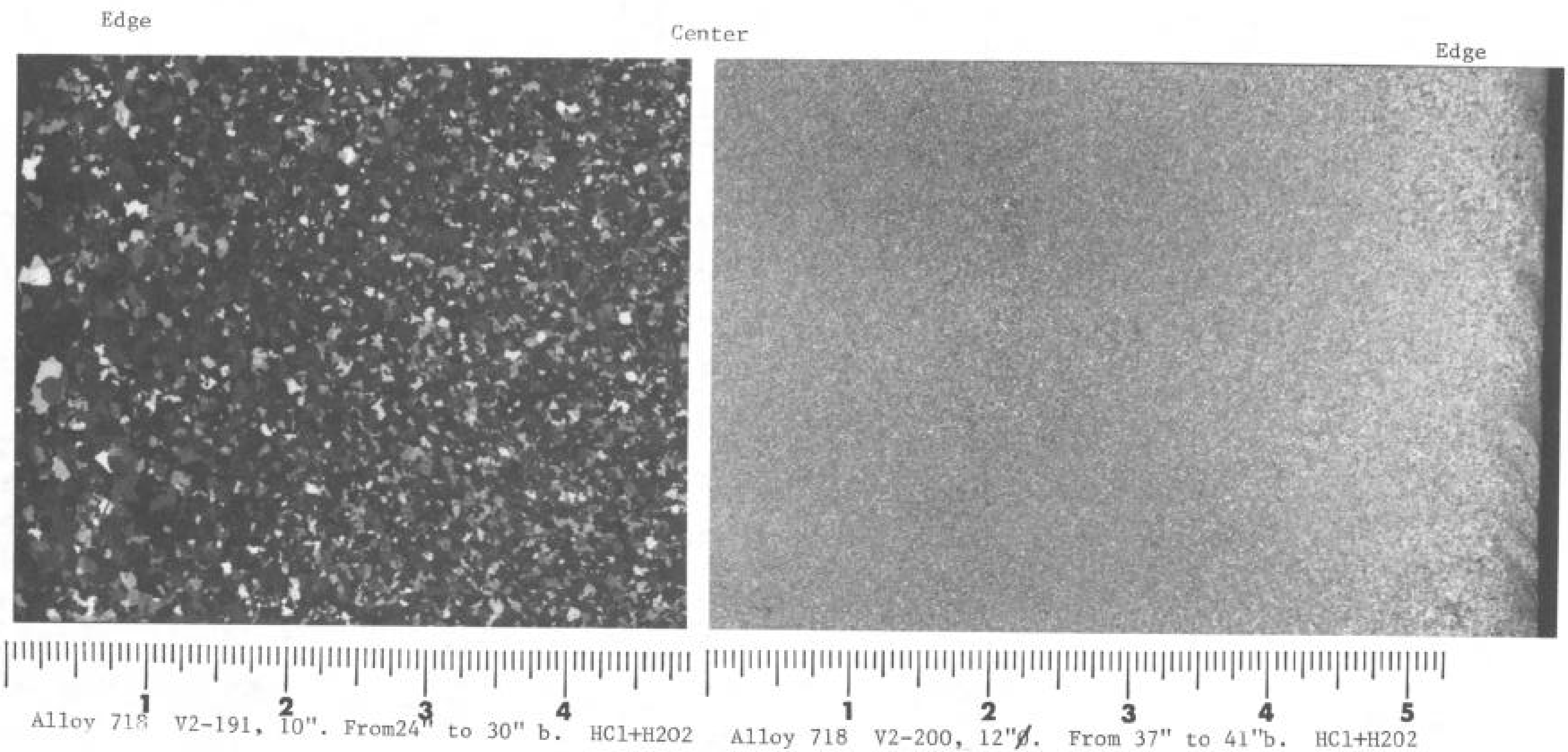
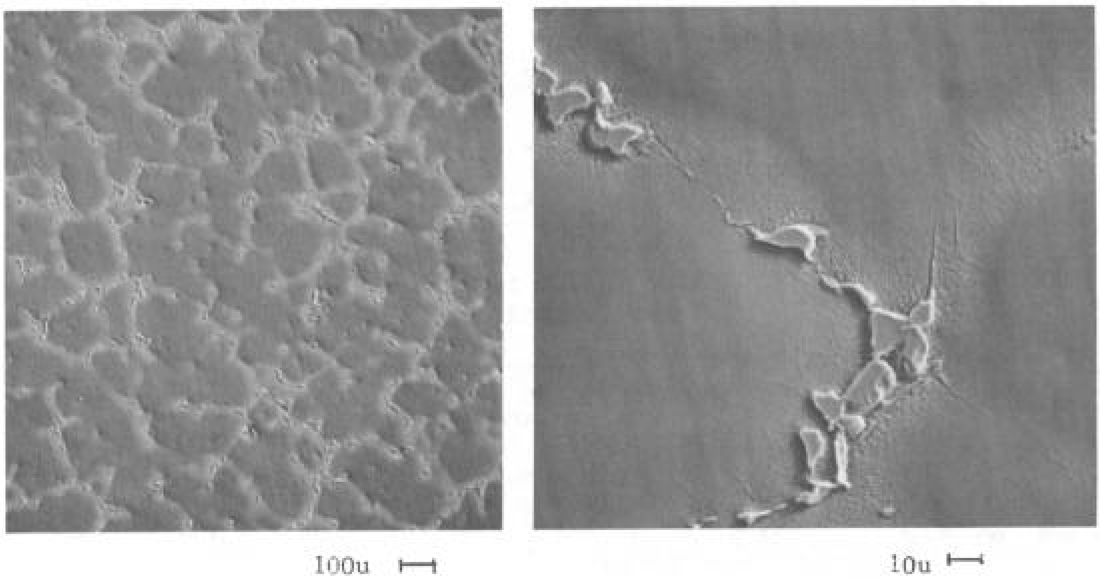
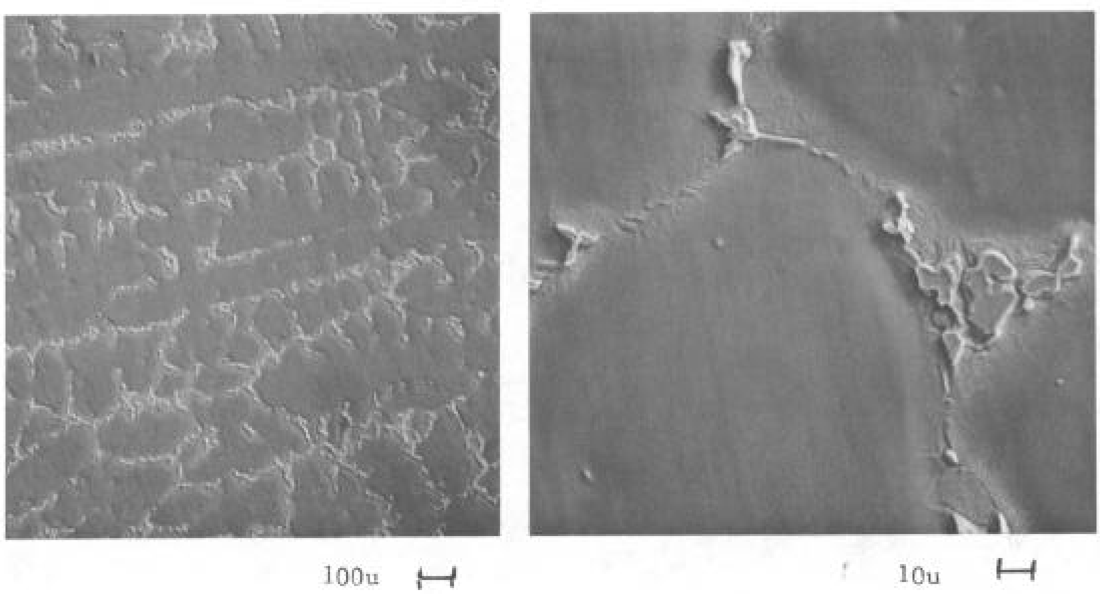


Figure 2. Longitudinal macro of 12" as cast and 10" homogenized VADER Alloy 718.

VADER melting is more energy efficient than VAR and ESR because none of the electrical energy is transferred to the molten pool. In conventional ESR and VAR processing, a considerable amount of the heat produced by the arc is absorbed by the solidifying ingot. This consumption of energy not only diverts heat from the electrode, it also reduces ingot cooling efficiency, which limits the melt rate. In VADER processing this lost heat is absorbed by the second electrode and fully utilized. The microstructural refinement realized in VADER ingots also holds the potential to reduce the cost of thermal mechanical processing of superalloys by increasing yield and reducing the work necessary to achieve structural refinement.



12"O VADER, center



20"O VAR, midradius

Figure 3. SEM of as-cast 12"ø VADER and 20"ø VAR ingot structure.

The Alloy 718 ingots described were continuous cast. This results in more constant casting and solidification conditions throughout the main melting step than occurs with VAR or ESR. The schematic of Figure 1 shows the principal features of the furnace and its operation. VAR billet alloys such as Waspaloy and 718 are used as convenient electrodes to develop process data and to determine the effect of melting and solidification variables on product characteristics such as grain size, surface quality and chemistry gradients.

This paper reports on the characteristics of Alloy 718 made from VADER ingots of 8, 10, and 12"ϕ cast up to 82" long and converted to 3½ or 5"ϕ billet by rolling. Ingots up to 9-inch diameter are rolled directly on the SMC rolling mill. Larger ingots are forged to an intermediate size then rolled to final size. The ability to melt and roll 8"-diameter ingots directly on the rolling mill means realistic small-scale experimental heats can be made quickly and also offers the potential for small diameter commercial products. The VADER furnace can also make commercial-size quantities up to a 4500-lb. ingot. The rolling procedures were selected to develop a uniform, fine grain size in the billet and to permit mechanical testing in the rolled billet as well as in a forged pancake.

Ingot Characteristics

Figure 2 shows the macrostructure of Alloy 718 as a 10"-diameter as-cast ingot and a 12"-diameter homogenized VADER ingot. The grain size as cast is 0.1mm (~ ASTM 3-4) and uniform edge to center. The ingot is sonic inspectable using a 2.25 mHz crystal. The ingots are given the standard homogenization for Alloy 718: 2150°F for 48 hours. The homogenized ingot has a grain size of 2.5mm in the outer inch of the ingot and 1mm in the balance, which is the common pattern with homogenized VAR ingot. The grain size in a homogenized 20" VAR ingot of Alloy 718 is considerably larger.

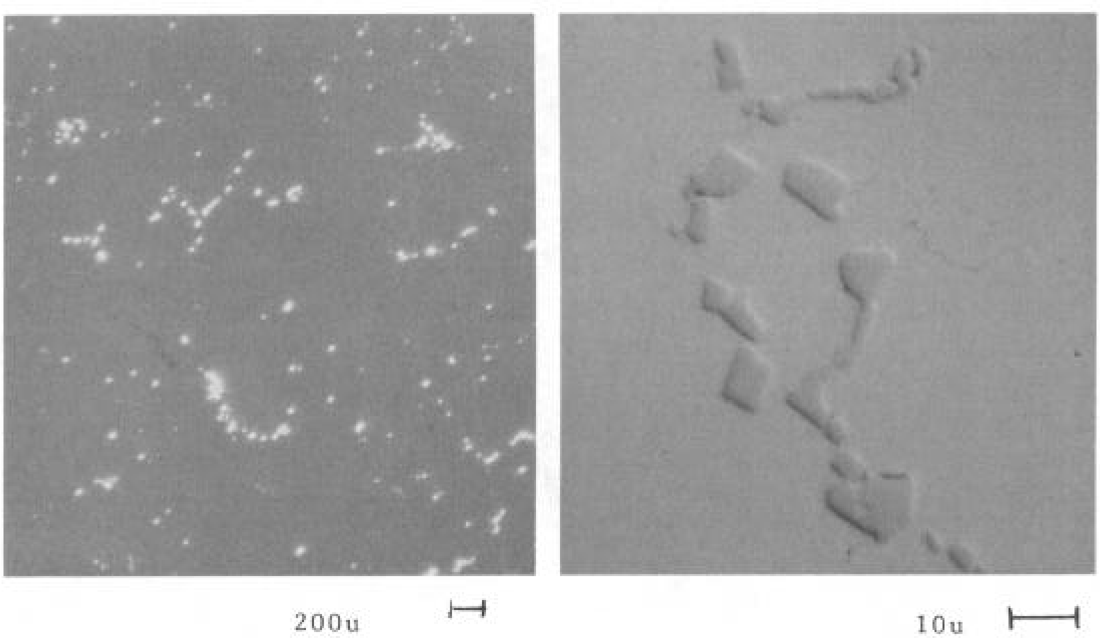


Figure 4. Carbide structure of homogenized 10"O VADER ingot. Center location, as polished.

The fine as-cast grain size that is achieved in VADER is the result of a high nucleation rate in combination with a relatively low solidification rate. Therefore, microsegregation in the ingot is similar to that seen in large-diameter VAR ingots. In Alloy 718, this means heavy local Nb segregation. Figure 3 shows microstructure of a 12"ϕ VADER ingot and a 20" VAR ingot. The samples were etched electrolytically in 20% H_2SO_4/MeOH. The absense of primary dendrite cores in VADER ingots means that homogenization is much more effective in reducing the chemistry gradients in the ingot.

After homogenization, the VADER microstructure consists of carbides and occasional nitrides which outline the original as-cast grain size. The pattern is shown at low magnification in Figure 4a; a typical carbide structure is shown in Figure 4b.

VADER casting has the ability to produce several chemistry gradients at both the ingot surface and the bulk of the ingot. These gradients are affected by casting parameters and are also a function of alloy. The gradients are the result of the flow of interdendritic fluid driven by solidification shrinkage and the centrifugal force from the rotating mold. Not surprisingly, Alloy 718 can show some dramatic gradients, especially Nb. The Nb, Fe and Cr gradients in two 12"ϕ VADER ingots are shown in Figure 5. The data in Figure 5 show dramatically the extent to which casting practice can affect the extent of edge to center chemistry gradients. The data in Figure 5a are typical of the product being evaluated for mechanical properties in this paper. The data in Figure 5b show the chemistry gradients resulting from changes in casting practice which also improved the surface quality and grain size of the ingot. These gradients can be modified to a degree, but present casting practice has not completely eliminated this condition.

Conversion

The homogenized ingots were converted to both 3½"ϕ and 5"ϕ billet by rolling. Eight-inch diameter ingots were rolled directly to size. Larger ingots, 10 or 12"ϕ, were first forged to 7¼" RCS, then rolled. Rolling procedures were used which produce a uniform, recrystallized fine-grain size when applied to product made from 20" VAR ingots. The grain size results are summarized in Table I along with typical data from VAR product. The poor results of the 5"ϕ billet made from the 8"ϕ ingot is mostly the result of a mill operating problem which required reheating of the billet partway through the rolling.

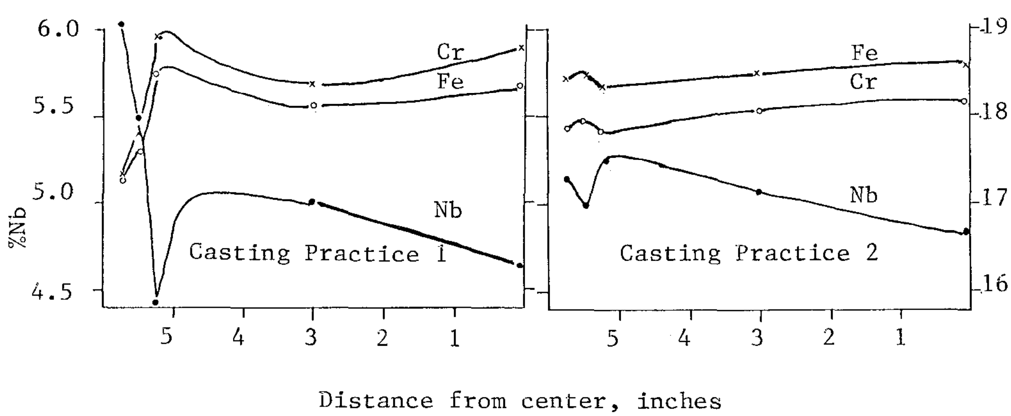


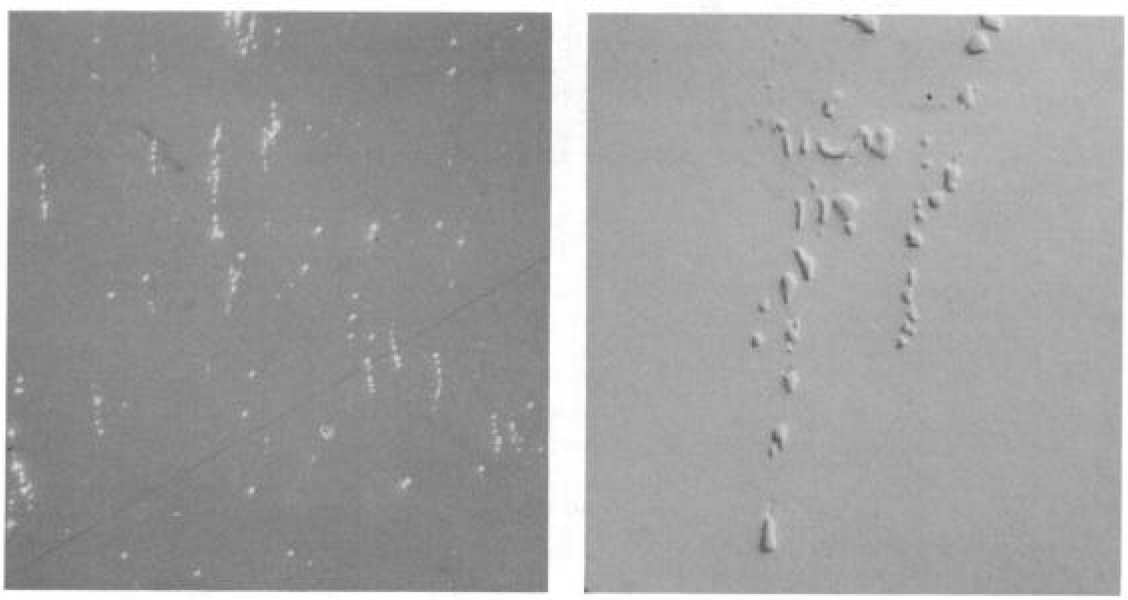
Figure 5. Edge to center Nb, Fe and Cr gradient in two 12"ϕ VADER ingots of Alloy 718.

Grain size in rolled billet is much more a function of thermal history and hot-working practice than ingot characteristics. Finish grain size is a function of starting grain size, total deformation and especially final deformation and finishing temperature. Dynamic recrystallization occurs in rolling and the final grain size is usually a fully recrystallized structure devoid of grain boundary delta precipitate. The results in Table I show VADER product to have an ASTM grain size number at the upper limit of what is obtained from 20" VAR ingot at the same final size. This may reflect an actual capability of VADER or it may also be a result of the way the billets were rolled. Being single pieces they were loaded in the front of the furnace. Therefore they had a short time at temperature in the coldest part of the furnace.

TABLE I. ROLLED BILLET GRAIN SIZE

COMPARISON OF VADER AND VAR PRODUCT

Ingot Size	Final Billet Size	Total Reduction	Center G.S.
8"φ VADER	3½"φ 5 "φ	4.8:1 2.3:1	6-7 6-7, 30%>00
12"φ VADER	3½"φ 5 "φ	10 :1 4.8:1	6-7 7
20"φ VAR	3½"φ 5 "φ	30 :1 14 :1	5, 3% ala 4 5, 3% ala 4



200u 10u

Figure 6. Carbide structure of 3½"Ø rolled billet from 8"Ø VADER ingot. Center, longitudinal.

TABLE II. MECHANICAL PROPERTIES

3½" AND 5"φ ROLLED BAR FROM VADER INGOT TESTED TO AMS 5662

A. **Properties in Billet**

1. Transverse testing, mid-radius location

Condition	Typical Properties From VAR Product	Test Results*
RTT		
UTS, KSI	195-200	193, 191, 192, 195
.02 YS, KSI	162-174	167, 165, 166, 166
% El	20- 26	20, 13, 17, 16
% RA	36- 48	34, 22, 27, 26

2. Longitudinal testing, mid-radius location
   1200°F/110 KSI SRN

Life, Hrs.	48-96 (10% notch failure)	1.3, 71, 63, 52, 52
% RA	10- 30	Notch, 9, 42, 7, 8

B. **Properties in Pancake**

1. Center transverse location

Condition	Typical Properties From VAR Product	Test Results*
RTT		
UTS, KSI	202-213	195, 196, 199, 200
.02YS, KSI	175-185	161, 161, 166, 166
%El	14- 20	24, 24, 20, 22
%RA	21- 34	29, 41, 34, 39
1200°F/110 KSI SRN		
Life, Hrs.	15- 60	69, 43, 67, 70
% RA	15- 33	46, 37, 15, 13

* One test each of four products

Typical carbide structures are shown in Figure 6. The carbide structure roughly approximates that found in billet made from 20"ϕ VAR ingot with a similar reduction. That is, the carbide structure more resembles the structure found in 6 to 10" diameter billet made from 20" VAR ingots than the structure in 3 to 5" diameter bar made from 20" VAR ingots. For all cases, the carbide morphology met all existing specification requirements of either the engine manufacturer or forging houses.

Properties

Room temperature tensile and notch stress rupture properties were tested to AMS 5662 in the rolled billet and in forged pancakes from the billet. The billet tests are mid-radius longitudinal and center transverse. The pancake tests are center transverse. Data are summarized in Table II and compared to similar product data from 20" VAR ingots. The tensile strength is at the bottom of the distribution when compared to either billet tests or pancake tests of similar products made from 20" VAR ingots. This is a reflection of the lower Nb level in the VADER ingot . The low transverse tensile ductility is a reflection of the carbide structure discussed above.

Because the ingot pool is exposed to the furnace atmosphere the VADER furnace is designed to have a high vacuum integrity. This was done to avoid the possibility of degrading the cleanliness of the metal during melting. The open geometry allows continuous, close monitoring of the ingot pool throughout casting. Observation of the pool surface on these and other melts indicates a high degree of metal cleanliness. Limited EB button testing supports the conclusion.

Conclusion

VADER ingots are much more structurally uniform on a macroscopic scale than VAR ingots. This structural uniformity is independent of ingot size in the range of 8 to 12" diameter and probably continues in larger diameter ingots. Continuous casting with cellular solidification produces this macro-uniformity and results in typical dendritic microsegregation. There are edge-to-center chemistry gradients which are a function of alloy and vary as casting practice is changed. The mechanical properties which are obtained in VADER melted Alloy 718 reflect the net reduction in Nb which results from the chemistry gradients which are developed in the ingot.