

DEVELOPMENT AND APPLICATION OF CM 718 PREMIUM SQ FOR
CRITICAL CAST STRUCTURAL COMPONENTS

G.L. Erickson, K. Harris, R.E. Schwer
Cannon-Muskegon Corporation
P.O. Box 506
Muskegon, MI 49443, U.S.A.

ABSTRACT

Alloy 718, developed by INCO in the late 1950's, is a weldable nickel base superalloy intended for use in gas turbine forged rotating disc and fabricated structural components. A recent trend is developing to investment cast structural components, rather than forge and fabricate. The cast components are typically required to demonstrate as much as 80% of the wrought product mechanical property capability, making casting integrity of utmost concern. This creates difficulty for precision casters since defect level tolerance in such castings is sharply reduced. Problems such as cast component soundness, inclusion level, post-heat-treat Laves phase content and alloy weldability are identified, and found to be associated with master metal quality. CM 718 Premium SQ, a grade of alloy 718 developed by Cannon-Muskegon, is particularly designed to resolve these problem areas. Superalloy vacuum induction melting (VIM) procedures, utilized to produce premium grade alloy, are reviewed along with specific alloy chemistry design criteria. More specifically, trace and tramp element effects in 718 are discussed in terms of component castability, mechanical properties and weldability. Improvements to these characteristics, being related to master alloy chemistry and melt process optimization, are shown for several difficult to cast, complex structural components.

NOMENCLATURE

DS - Directional Solidification
VIM - Vacuum Induction Melting
VIR - Vacuum Induction Refining
CM - Cannon-Muskegon
IW - Integral Wheel
SQ - Super Quality
 γ - Gamma
 γ' - Gamma Prime [$\text{Ni}_3(\text{Al}, \text{Ti} \dots)$]
 γ'' - Gamma Double Prime (Ni_3Cb) -- bct
 δ - Delta (Ni_3Cb) -- orthorhombic

ΔG - The Change in Gibbs Free Energy for a Reaction
 ΔG° - The Change in Gibbs Standard Free Energy for a Reaction
R - The Universal Gas Constant
T - Absolute Temperature
 $P(\text{CO})$ - Partial Pressure of (CO)
 $a[\text{C}]$ - Activity of [C]
 $a[\text{O}]$ - Activity of [O]
PWHT - Post Weld Heat Treatment

INTRODUCTION

Superalloys are a group of Ni-, Fe-Ni- and Co-based alloys which exhibit outstanding strength at temperatures as great as 85% of their melting points ($0.85 T_M$). The alloys, generally in use at temperatures in excess of 1000°F, have evolved over the last 50 years, having been initially developed for usage in aircraft piston engine turbo-superchargers. Their development has since been paced by demands of advancing gas turbine engine technology.

Initial U.S. cast superalloy developments centered around Co-based materials. Cast Vitallium or Co 21 (Co-27 Cr-5.5 Mo-2.5 Ni-.25C) turbo-supercharger blades were produced by the Austenal Company in 1942 in response to an overloaded forging industry, ultimately leading to the successful manufacture of investment cast components for the first U.S. production gas turbine engine in 1945 (Ref. 1). Concurrent to these developments and as early as 1939, wrought Ni-Cr-Fe solid-solution alloys were developed. This work led to the addition of aluminum and titanium to Ni-based alloys for γ' strengthening, which eventually presented the need to investment cast the materials due to their decreasing forgeability.

Cast Ni-based alloy developments outpaced Co-based development work by the late 1950's due to their superior strengthening potential, viz stable, coherent

intermetallic compound (γ') introduction. The advent of commercial vacuum induction melting and vacuum investment casting in the early 1950's contributed to the momentum resulting in many fast-moving, highly rewarding Ni-based alloy developments up through the 1960's (Fig. 1).

The result of component behavior/life being more predictable was two-fold. First, it resulted in the design of components operating at much greater percentages of the materials capability and second, it made the production of such items more difficult since microstructural control and casting cleanliness became increasingly crucial.

PROGRESS IN TURBINE BLADE MATERIALS

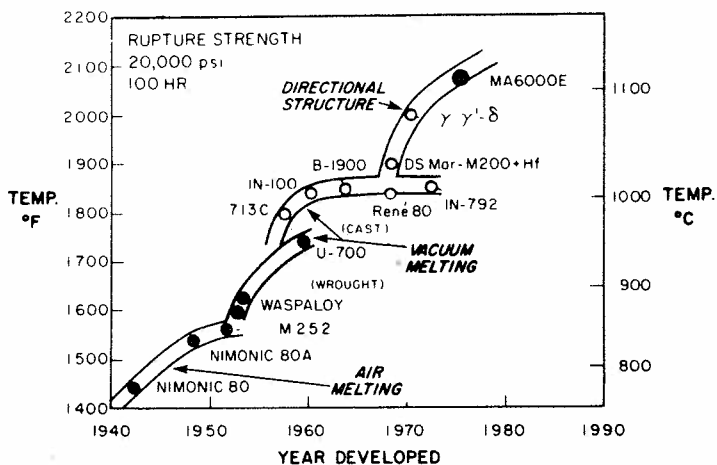


Figure 1. Progress in the Temperature Capability of Superalloys in the Last 40 Years (Ref. 2).

New alloy development continued through the 1970's, however, at a somewhat more moderate pace. Instead, efforts were placed more toward process development, e.g., directional solidification, single crystal solidification and powder metallurgy.

Whereas most previous alloy design work was centered primarily upon controlling grain boundary condition and increasing fine γ' volume fraction - with seemingly little attention given to alloy castability and ancillary property goals - the alloys developed for the evolving DS, single crystal and powder processes were designed with more consideration toward commercial producibility. This approach, fortunately, resulted in more knowledge of the effects of minor elements and master metal quality on foundry performance and component durability, due to the difficulties encountered in developing alloys for these specific processes.

The advent of the new process technologies, particularly DS and single crystal casting, allowed for dramatic increases to gas turbine engine hot-section operating temperatures and rotational speeds, thereby increasing overall engine efficiency. With ultimate component life being less a function of grain boundary condition and more related to γ - γ' strengthening mechanisms, the predictability of such became much easier.

For these very reasons, it has become mandatory for the master alloy producers and the investment casters to work closely toward maximizing alloy performance in a given application. Such an approach was undertaken by Cannon-Muskegon toward optimizing vacuum induction melting (VIM) procedures to assist investment casters in achieving stringent mechanical properties design criteria while also meeting economic constraints.

The development of CM 718 Premium SQ is reviewed, where stringent controls exercised upon selected tramp elements and optimized melt practice result in drastically reduced casting level of inclusions and agglomerated microporosity, while also providing capability for complete Laves phase transformation and increased weld integrity. Note that the subject program is ongoing and as such, what follows represents an interim report.

VACUUM INDUCTION MELTING

Process Background and Concepts

Commercial vacuum induction melting began in the early 1950's, having been stimulated by the need to produce the emerging reactive element containing superalloys within an evacuated atmosphere. The process is relatively flexible, featuring independent control of time, temperature, pressure and mass transport through melt stirring. As such, VIM offers more control over alloy composition and homogeneity than all other vacuum melting processes.

The primary purification reaction occurring in the process is the removal of melt contained oxygen by means of reaction with carbon, $[C] + [O] = (CO)$, this being more effective than thermal dissociation of the metal oxides. The reaction occurs most readily at or near the melt surface since the ferro-static head inhibits deoxidation in the actual body of the melt. The kinetics of the reaction are thereby affected by crucible geometry and melt stirring.

Again, considering the reaction $[C] + [O] = (CO)$ and that the free energy of the reaction is represented by $\Delta G = \Delta G^\circ + RT \ln \frac{P(CO)}{a[C] \cdot a[O]}$

it is seen that the removal of oxygen from the melt as (CO) is favored by decreased melt chamber pressure [where the melt chamber (CO) partial pressure < the melt dissolved P(CO)], elevated bath temperature and increased carbon activity (Ref. 3).

Of course, it must be recognized that the melting crucible material is not inert and actually is another source of [O] and other impurities, dependent upon refractory type and condition. Therefore, melt refine temperature and length of refine must be carefully scrutinized. Additionally, since melt stirring is an integral part of the deoxidation process, it must be optimized through furnace frequency and also proper power application procedures so as not to cause refractory lining erosion -- a potential problem particularly during the controlled, but more vigorous, (CO) boiling portion of the process.

Continuing with the VIM deoxidation process, i.e., the generation of the CO gas, there is general agreement that the CO bubbles are nucleated heterogeneously along the walls and sometimes bottom of the melt/lining refractory interface -- perhaps at small crevices existing in the lining -- and grow during movement toward the molten metal/vacuum interface (Ref. 4, 5, 6) (Fig. 2). Actual bubble formation is dependent upon the number of gas molecules present, the pressure in the liquid at the level of the bubble, the temperature of the gas, and for very small bubbles, the interfacial tension between the gas and the liquid metal.

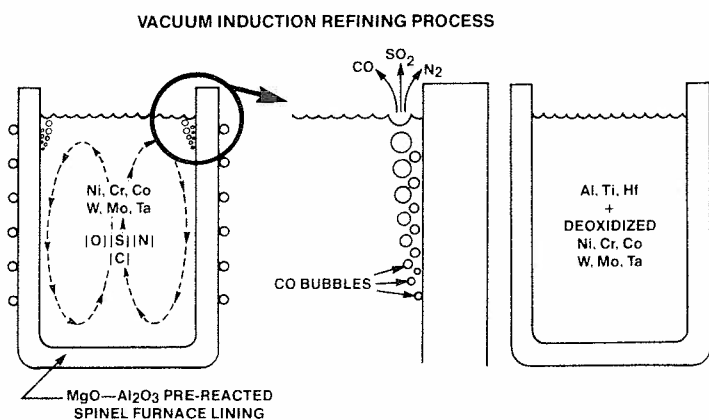


Figure 2.

Following formation, bubble growth and mass transport within the liquid toward the liquid/vacuum interface is dependent upon the quantity of the dissolved gas, the decreased pressure exerted on the bubble as it rises in the melt, the bath temperature and the time it takes for the bubble to rise through the melt to the surface, which in itself, is a function of melt stirring, the pressure above the melt,

and also, for relatively small bubbles, the interfacial tension between the bubble and the liquid metal.

The relatively vigorous, but controlled, portion of the boiling process quite naturally is the period resulting in the greatest (CO) loss. Concurrently, some nitrogen loss is realized due to scavenging associated with the (CO) bubbles and possibly slight sulfur reduction during the (CO) "super-saturation" stage via SO₂ evolution. Additionally, it should be noted that the evaporation of minor elements such as Pb, Ag, Bi, Se, Te and Tl which are deleterious to alloy elevated temperature rupture strength and ductility (Ref. 7, 19, 20), also occurs during this period as well as throughout the entire refine (Ref. 8) (Fig. 3). Obviously, elements such as As and Sn must be controlled through raw material selection since they are not removed by vacuum refining.

EVAPORATION of ELEMENTS from 80% NICKEL/CHROMIUM ALLOY

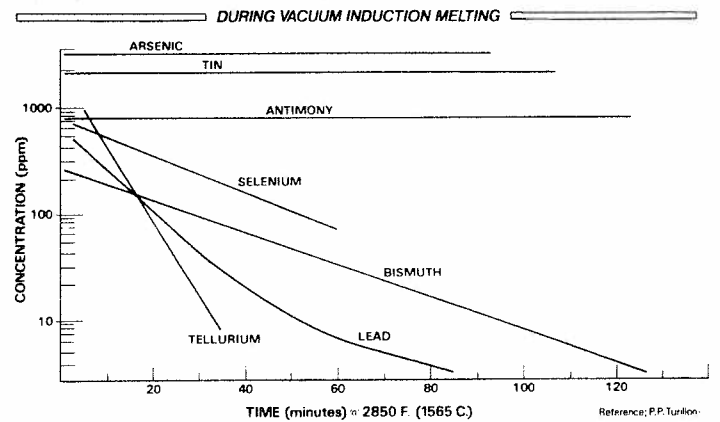


Figure 3.

Once the boiling subsides, surface desorption of additional (CO) occurs, and it is during this non-boiling period that nitrogen removal (desorption) is most effective (Ref. 9).

CM VIM Process Characterization

Cannon-Muskegon operates three VIM units with respective charge weight capacities of 400, 2800 and 8300 pounds, further being identified as the V-1, V-2 and V-3, respectively (Figs. 4, 5). Quite naturally, the V-1 is utilized primarily for development purposes, i.e., for lining refractory development, raw material evaluation, melt procedure development, and also to assist alloy developers with the scale-up of new emerging alloys, e.g., single crystal. The V-2 unit is utilized to produce materials which are normally used in non-critical static appli-

cation and/or those which may require relatively fast, batch pouring due to high melting point consideration.

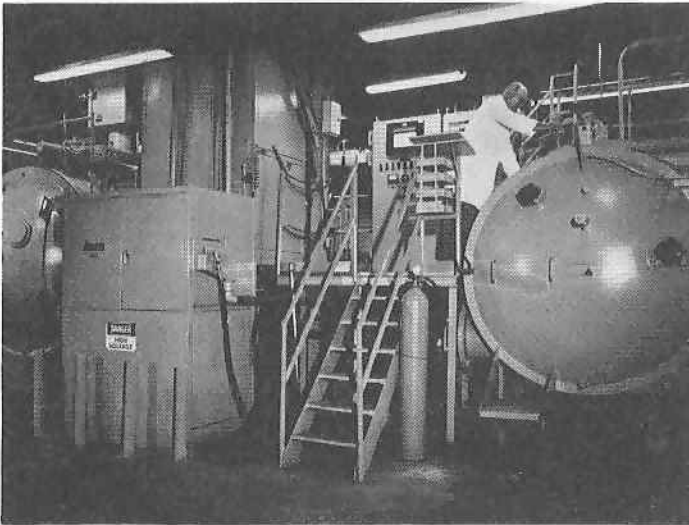


Figure 4. CM V-1 and V-2 VIM Units (right to left)

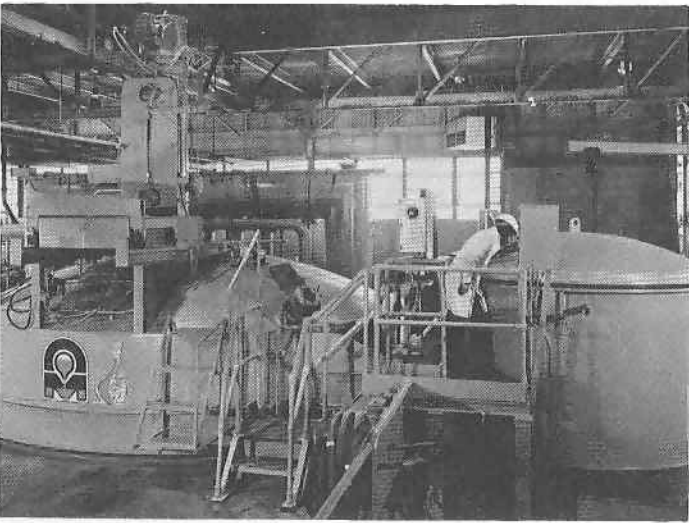


Figure 5. CM V-3 VIM Unit

The V-3 furnace is used to produce a wide range of the existing Ni-based and Co-based superalloys. The basic thermochemical considerations already discussed are gainfully applied to produce all of the CM VIM products. Collaborative work with lining refractory suppliers and the inhouse optimization of lining installation and fritting techniques resulted in the relatively unreactive, high bond strength, high purity $MgO - Al_2O_3$, fluxed spinel lining utilized by CM. By minimizing extremes in thermal cycling, optimizing alloy sequencing, refining temperature, time and pressure, alloy which is practically void of any lining related non-metallics is produced. The types of raw materials used vary

upon the quality of alloy to be produced, as does the melt procedure. Those alloys which are destined for critical application and may be difficult in terms of foundry performance are produced utilizing the highest quality raw materials commercially available and undergo more sophisticated melt processing. Those which are for "commercial" application, e.g., GMR 235 or 713C going into turbocharger wheels, are manufactured using lower quality raw materials (perhaps even select materials) since the higher quality alloy product is not necessary. The more sophisticated alloy systems are generally produced to "SQ" or "IW" quality levels, with special attention not only given to cleanliness but also to specific microstructural characteristics and/or chemistry requirements to assist foundry performance, weldability and component mechanical properties.

Base charge materials are layered in the relatively warm furnace, the location of such dependent upon melting point and bridging tendency. Only those materials whose oxides are relatively easily reduced for the melt conditions to be encountered -- as indicated by the Richardson and Jeffes diagram (Fig. 6) -- are placed in the initial furnace charge, along with a small, controlled C addition. Also, those elements which have a particularly strong

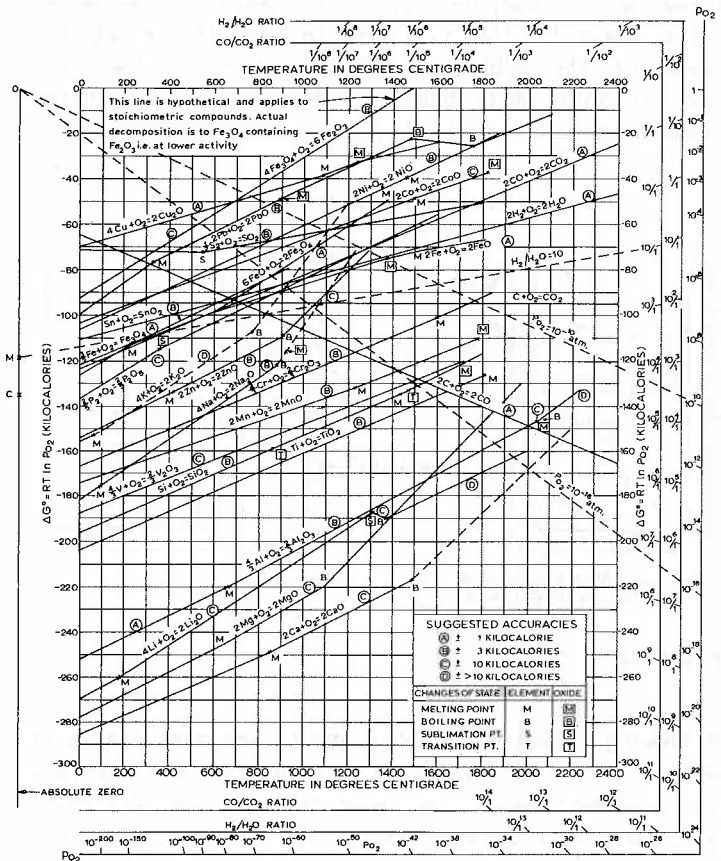


Figure 6. The Richardson and Jeffes diagram for the standard free energies of formation of metallurgically important oxides.

affinity for nitrogen according to Figure 7 may be held from the base charge due to their effect of lowering the activity of the dissolved nitrogen.

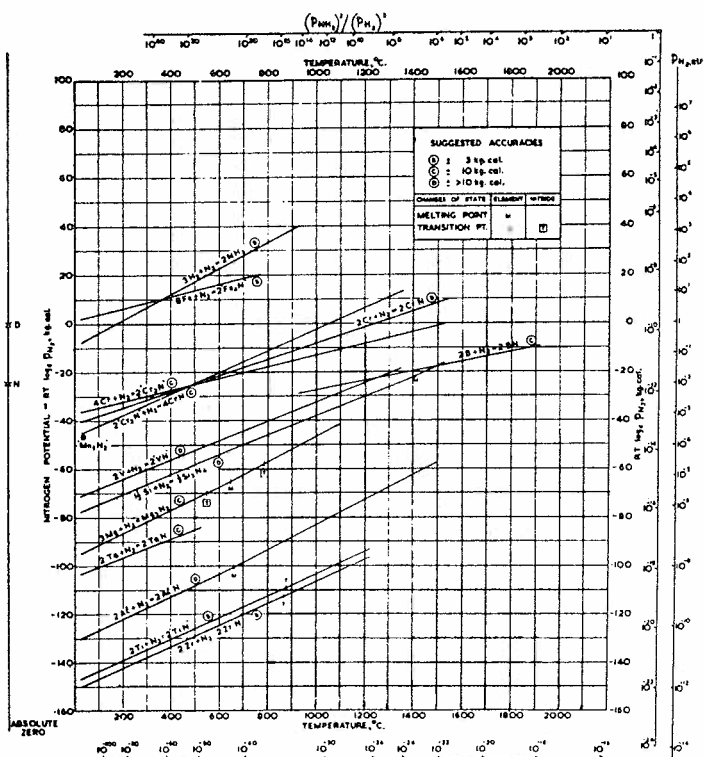


Figure 7. The standard free energy of formation of many metal nitrides as a function of temperature (Ref. 10).

Following furnace evacuation and particular heat-up cycles which ensure proper closure of any refractory lining cracks prior to metal liquation, optimum temperature and vacuum pressure, consistent with promoting a somewhat vigorous (CO) boil, is attained. Refining of the bath is undertaken at a temperature and for duration long enough to reach the so-called system equilibrium conditions, the assurance of which is provided by the attainment of consistent furnace leak-up rates. At this point, those elements which were held from the base charge due to their relative reactivity toward oxygen, e.g., Al, Ti, Zr and Hf, are added with associated solutioning and homogenization procedures.

Dip sample alloy chemistry is checked in a relatively short time period with Siemens MRS 400 X-ray fluorescence equipment and a Leco CS 244 fluxed, oxygen fusion C and S analyzer. Corrective additions are made with appropriate bath solutioning. Chemistry check prior to pouring is undertaken in a similarly rapid manner.

Pouring proceeds once the correct chemistry is assured, the bath is properly solutioned/homogenized and the proper pour temperature is attained. Pouring

of the molten metal, being undertaken under high vacuum condition, proceeds from the furnace crucible into a relatively sophisticated multi-compartment tundish, which ensures that extensive time for flotation is achieved and that laminar flow conditions prevail in the final separation and pour compartments. The flow-rate controlling, high-alumina tundish system results in a pouring rate which is probably among the slowest in the industry.

Because of the characteristically slow pour rate achieved with the V-3 furnace pouring system, together with the inherent cleanliness of the CM VIR material, neither extruded or reticulated foam filtration is necessary. High-alumina ceramic foam filtration, however, is utilized on the CM V-1 furnace where pouring is a batch process and metal flow-rate is approximately four times greater than that of the V-3. Such flow rate does not allow adequate time for flotation of melt suspended dross or condensate particulate picked-up during pour, thus making filtration attractive. In fact, V-1 furnace metal quality is improved by utilizing filters; however, the metal quality, in terms of cleanliness, still doesn't exceed that produced in the V-3 unit -- product which shows cleanliness superiority compared to industry ceramic foam filtered materials (even Hf bearing alloys).

Five years experience with high alumina foam filters suggest they are most effective where extremely high pour-rate conditions and gross problems with cleanliness prevail. Foam filters generally exhibit relatively poor mechanical strength, with some also possessing relatively poor thermal shock resistance. Extreme variation in filter performance within given batches has been experienced.

Foam cell particle breakage, resulting from handling during shipment or tundish installation, quite naturally results in filter particulate in the alloy bar stock, and if undetected, in the castings produced. It is contended that many in the industry are using filters to "mask" problems which exist within their melt process, and that such will lead to progressively poorer alloy quality. Ceramic foam filtration is by no means the cure-all to poor VIM practice.

CM 718 PREMIUM SQ DEVELOPMENT

Background

The alloy 718 was developed by INCO in the late 1950's primarily for fabricability and more particularly, weldability. To that end, the alloy contains approximately 5.0% Cb, with its characteristic properties gained primarily through means of γ'' (Ni₃Cb)

precipitation as opposed to other common Ni-based alloys which are more dependent upon γ' (Ni_3Al , $\text{Ti} \dots$) precipitation strengthening.

Stoichiometrically, γ' and γ'' are nearly identical. However, γ' is a face centered cubic precipitate, whereas γ'' is a body centered tetragonal, with both being precipitated from a face-centered cubic matrix. Being that the atoms of the γ' precipitate occupy the same lattice sites as the atoms in the solid solution, γ' precipitation is found to be rapid and uniform. But for the γ'' precipitation, complete rearrangement of atom sites as well as compositional changes must occur, making transformation relatively slower than that which occurs with γ' precipitation (Ref. 11).

It is this slowed rate of transformation of the γ'' , allowing for considerably more weld zone stress relief prior to precipitation hardening and associated loss in ductility, which makes the alloy 718 much less susceptible to PWHT (post weld heat treatment) cracking than γ' strengthened materials (Ref. 12). However, Owczarski cautions that 718 is not entirely void of PWHT cracking problems when welded in heavy sections or highly restrained configurations, nor is the alloy devoid of hot HAZ cracking (Ref. 13). It has been seen that if compositional tolerances are allowed to deviate much from the optimum and minor element content is permitted to increase, the alloy could be particularly prone to hot shortness during welding (Ref. 14).

Others who have studied hot crack susceptibility of 718 found that constitutional liquation of CbC particles and the subsequent resolidification of liquated grain boundary regions to be the key to understanding the HAZ cracking mechanism in 718 (Ref. 15). The severity of the hot cracking susceptibility is apparently dependent upon the amount and distribution of the intergranular liquid, with it further postulated to be an effect of the amount and distribution of Cb available to the liquated grain boundaries (Ref. 15), with Laves phase precipitation occurring during cooling. The same grain boundary liquation was found in IN600 and felt to be accentuated by impurities such as P and S when segregated intergranularly since they affect (increase) wetting behavior in the liquated regions, due to reduction in the effective solidus and liquidus coupled with a decrease in the solid-liquid interfacial energy, thereby making elemental entrapment, such as Cb, more likely (Ref. 16).

Weld cracking problems occurring in other structural materials have also been associated with localized HAZ melting of grain boundary regions containing inclusions or other minor phases (Ref. 17, 18). Many trace elements such as S, Pb, Bi, Se, Te, Tl, As and Sn, when present even in levels of just a

few ppm, were shown to migrate to grain boundary regions, drastically reducing elevated temperature ductility and rupture life in Ni base alloys (Ref. 7, 19, 20). (Figs. 8 and 9).

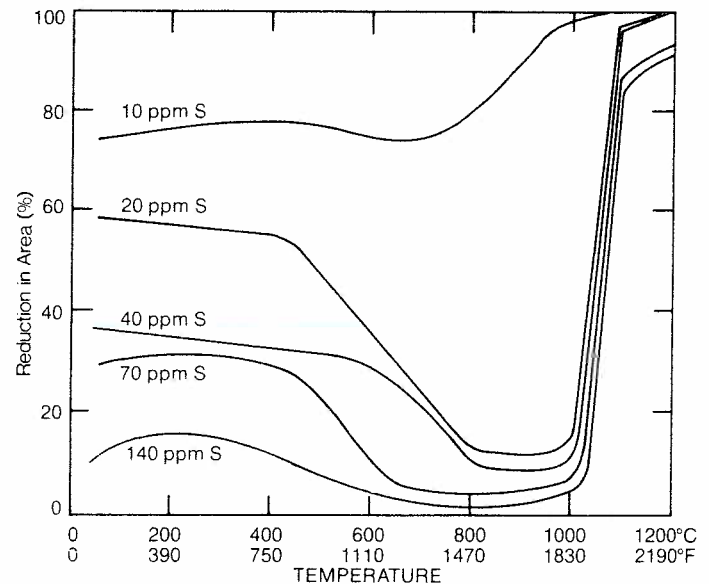


Figure 8. Tensile ductility of Ni-S alloys between 120°F and 2190°F.

Source: Lozinskiy, et al.

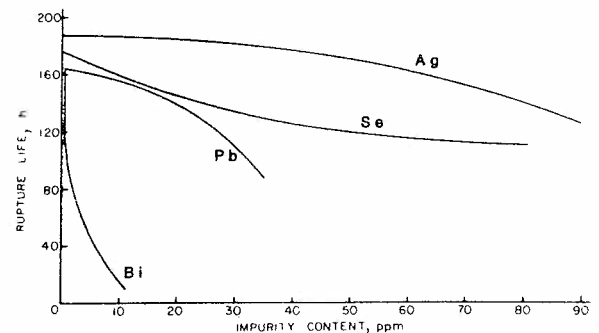


Figure 9. Effect of Various Trace Elements on the 1200°F/100 ksi Stress-Rupture of IN-718 (Ref. 20).

It is an unfortunate consequence that some of the elements which are added to Ni-based alloys to increase stress-rupture life, e.g., B and Zr which tend to segregate to grain boundaries, increase the tendency for cracking in the fusion and HAZ's of the base metal being welded (Ref. 21, 22, 23). It is also unfortunate that the effects of the aforementioned elements (including S, Pb, Bi, Se, etc.) to alloy weldability are additive, thereby making the likelihood of cracking during restraint-weld fabrication and/or general weld repair quite likely without rigorous minor element control having been undertaken.

Sensitivity to these problem types was apparent in components investment cast from the alloy 718. Major difficulties associated with gross weld HAZ cracking occurred in large, complex, critical structural castings. Additionally, many investment casters reported extremely high levels of casting inclusions requiring dressing and welding, besides also most likely contributing to cracking problems.

The result of such was two-fold. First, investment casters began to realize that many castings they produced required several inspection-rework-inspection cycles prior to meeting part quality criteria. The extra time spent, plus the expensive materials utilized for grinding and inspection, not to mention labor for those castings scrapped following many inspection cycles or during component machining, resulted in disappointing "bottom-line" costs to the casters. Secondly, engine producers have had to carry the burden of these problems through higher component costs and compromised quality.

Therefore, Cannon-Muskegon developed a grade of 718, designated CM 718 Premium SQ, designed to resolve/minimize the problems mentioned, while also addressing alloy castability and mechanical properties attainment. The types of structural components the material was targeted for are indicated in Figures 10, 11 and 12.

Design Criteria

Melt procedure and raw material selection was optimized to promote the following characteristics in the precision castings:

- Soundness in terms of as-cast microporosity level
- Minimized inclusion content
- Weld integrity
- Minimized post-heat treatment Laves phase content

To this end, the following elements were controlled as indicated and for the accompanying reasons:

- Si, controlled to < 100 ppm.
Si impedes the rate of Laves (Ni_2Cb) phase transformation (Ref. 24). Maximizing Laves phase transformation is desired due to its adverse effect on mechanical properties and possible effects to weldability. Si has also been seen to cause hot-short cracking during welding of Ni alloys (Ref. 21).
- S, controlled to < 20 ppm.
S tends to segregate to grain boundaries, thereby decreasing hot ductility and promoting cracking (Ref. 19, 21, 22). S, at higher levels, may also cause increased alloy/crucible wetting during precision casting.

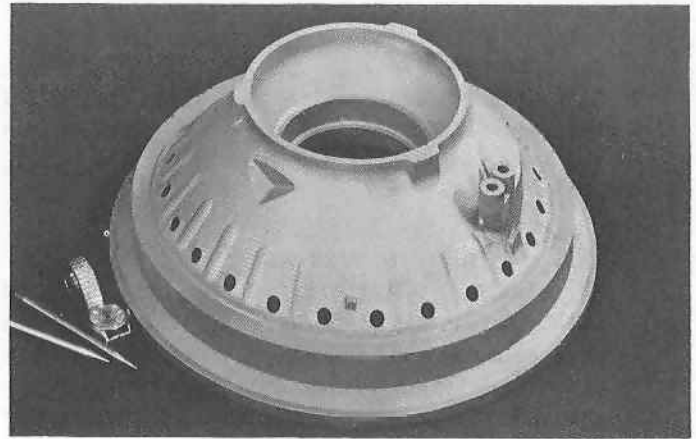
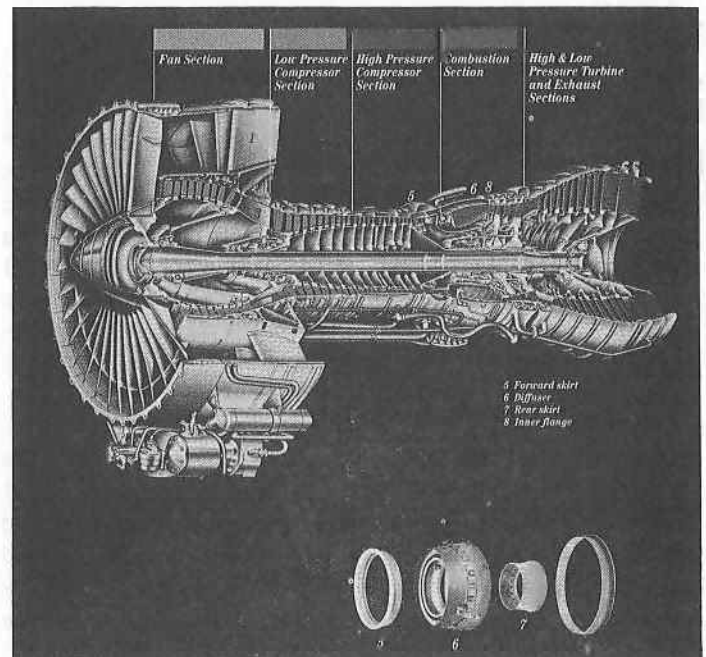


Figure 10. Structural component for which CM 718 Premium SQ is under evaluation.



Figure 11. Difficult compressor stator ring for which CM 718 Premium SQ is utilized in production.



PW 2037 ENGINE SCHEMATIC ILLUSTRATING POTENTIAL CM 718 PREMIUM SQ APPLICATIONS
Source: Precision Castparts Corp. 1983 Annual Report

Figure 12.

- Zr, controlled to < 10 ppm.
Zr tends to segregate to grain boundaries and increase the tendency for cracking in the weld and HAZ of the base alloy (Ref. 21, 22).
- [N], controlled to < 20 ppm.
[N] induces microporosity in castings and with sufficiently high [N], agglomerated microporosity occurs (Ref. 25). [N] also promotes alloy/crucible wetting during precision casting operations. High levels of [N] promote the formation of titanium-carbonitride inclusions.
- [O], controlled to < 5 ppm.
Alloy contained [O] is present as non-metallic stable oxide inclusions which affect weldability and mechanical properties (Ref. 17, 18).
- Cb, stringent controls are exercised.
Helps control the level of Laves phase formation.
- C, stringent controls are exercised.
Affects alloy fluidity, weldability and carbide characteristics.

Figure 13 details the actual trace element levels attained for the twenty-nine heats of CM 718 Premium SQ produced to date, the product of which is either under evaluation or in production at ten leading U.S. precision casters.

Results and Discussion

The CM 718 Premium SQ product evaluation has progressed considerably. Results have been encouraging, with all investigators reporting significantly lower inclusion level based on side-by-side comparison to alternate alloy 718 sources. Metallographic evaluation of several CM 718 Premium SQ casting types showed increased weld integrity and level of Laves phase transformation. Additionally, the material exhibited relatively low casting microporosity level when proper pouring temperature was utilized.

Metal quality has therefore been found to be the primary variable affecting casting quality in several optimized foundry processes. Side-by-side wax and shell production plus metal pouring, both with and without disposable crucible liners and ceramic filter usage, has shown CM 718 Premium SQ to provide the cleaner castings.

The structural component illustrated in Figure 10 was utilized to evaluate cleanliness of three alloy

CM 718 Premium SQ Grade Alloy					
Selected Trace Element Chemistry Highlights					
Heat No.	[N]	[O]	Si	S	Zr
V6622	19	4	< 200	26	< 10
V6628	18	4	< 200	15	< 10
V6644	30	4	80	29	< 10
V6645	22	3	70	21	< 10
V6662	17	3	70	12	< 10
V6667	14	4	60	11	< 10
V6683	15	2	70	9	< 10
V6711	13	3	70	9	< 10
V6712	13	3	60	11	< 10
V6713	13	2	60	11	< 10
V6714	16	2	80	7	< 10
V6715	12	2	30	10	< 10
V6738	15	4	50	8	< 10
V6739	12	4	60	8	< 10
V6740	10	4	70	8	< 10
V6741	9	4	60	8	< 10
V6742	10	4	50	9	< 10
V6749	11	3	40	7	< 10
V6750	11	3	50	8	< 10
V6753	14	3	50	9	< 10
V6754	14	4	30	9	< 10
V6755	12	3	40	9	< 10
V6756	13	3	50	9	< 10
V6757	14	3	40	8	< 10
V6759	15	3	< 100	8	< 10
V6760	12	5	< 100	11	< 10
V6761	14	5	< 100	9	< 10
V6762	15	4	< 100	11	< 10
V6783	14	4	70	13	< 10

Analyses in wt. ppm.
8300# Production Heats.

Figure 13.

sources, i.e., 1) CM 718 Premium SQ, 2) an alternate VIM 718 source, and 3) alternate VIM + EB (electron beam) remelted material. Fifty castings were produced with each alloy grade -- six castings per grade per lot. Eight casting lots were undertaken over a period of six months, making shell problems discernable through total program review.

Preliminary review showed the CM 718 Premium SQ material superior to both the VIM + EB alloy and the alternate VIM 718 source. These initial results showed rework level (time) was reduced -- as compared to the production standard -- by greater than 50%

with the CM 718 Premium SQ and by 15-20% with the EB remelted material, whereas the third alloy grade showed an increase to rework necessary. It is anticipated that additional data assimilation along with the recognition of two process related problem areas discovered, only affecting the CM 718 Premium SQ remelting, will result in even greater advantages gained with the CM material.

Thirty-two of the casting type illustrated in Figure 14 have been produced with CM 718 Premium SQ material.

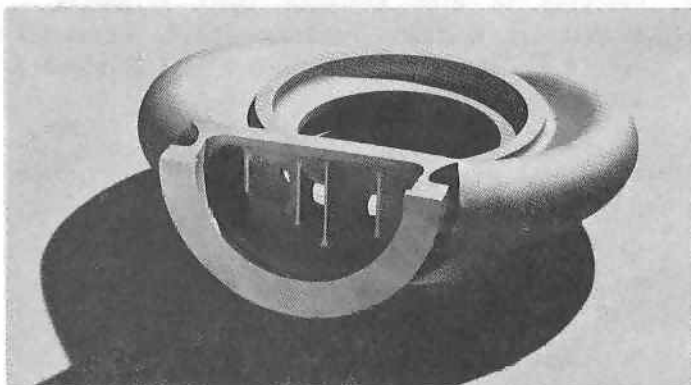


Figure 14. Complex component utilizing CM 718 Premium SQ material.

Initial evaluation centered around the comparison of eight castings produced with the CM alloy to one cast with the previously standard material. The inclusion level apparent for the one manufactured with the previously standard material typified the normally attained cleanliness level, being found to reflect 50 indications requiring repair following fluorescent dye penetrant inspection. On the other hand, though, the eight castings produced concurrently with the CM 718 Premium SQ alloy showed an average 2-3 indications in zyglo, some of which were shell related.

Due to similar success prevailing with the CM material during subsequent manufacture of the same component, the precision caster now utilizes the CM 718 Premium SQ alloy in another difficult volute component application, with thirty-nine produced, thus far. Similar casting cleanliness results were achieved, resulting in much less time spent reworking and "mapping" welded regions.

Another investment caster produced ten castings of a complex configuration, five of which the CM 718 Premium SQ was utilized, with the remaining using an established grade of material. The castings were poured in the same furnace, alternately, with shell materials and the like having been from identical batches and all variables under control.

The results, according to the precision caster, were as apparent as "night and day". Having placed

the ten castings in zyglo without obvious identification, five "lit-up" similar to what a shot-gun peppering effect would appear, whereas the remaining five were dark blue with no apparent inclusions. Check of the identity revealed the castings free of any inclusions were those founded with the CM 718 Premium SQ stock. Needless to say, casting shipment followed pouring faster than ever before.

Metallographic evaluation of other complex configuration castings produced with CM 718 Premium SQ also showed ultra low inclusion level. Similarly, indications were that favorable casting microporosity level was achieved when pouring temperature was optimized by undertaking heat solidus determination prior to production release. In one case, CM 718 Premium SQ exhibited a 40-45°F lower solidus temperature than another alloy source material which had been used to develop pouring parameters, this resulting in too much superheat utilized in the pouring operation, which definitely increased propensity for microporosity. Subsequent pour temperature adjustment resolved the problem.

Complete Laves (Ni_2Cb) and δ (Ni_3Cb) phase transformation was achieved in the component illustrated in Figure 11 with such transformation likely to occur in larger sectioned components, as well. Finally, component weld integrity was increased with the CM 718 Premium SQ material, but not to the desired level. A program to further address weldability (aim chemistry modifications) was begun.

CONCLUSION

Cannon-Muskegon has developed a vacuum induction melting process specifically tailored to producing ultra-clean alloy. Through technical contact with precision casters and turbine engine manufacturers, industry needs were recognized and applied toward producing alloy product to assist precision casters to better optimize component producibility and durability, while meeting economic constraints. One such development effort, CM 718 Premium SQ, was presented in part, with further program results forthcoming.

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