## HISTORY OF CAST INCO 718

Oren W. Ballou and Melvin W. Coffey

Casting Design Manager and Process Engineering Manager
Production Development Engineering
Large Structurals Business Operation
Precision Castparts Corporation

## Abstract

PCC entered the Large Structurals Casting business for aircraft engines in 1965. Large castings were 24 inches in diameter with a ship weight of 50 pounds and made of IN-718. By the late 1970's, large castings were 50 inches or more in diameter with a ship weight of 350 pounds. During that time period dimensional requirements and part quality became much more stringent. In order to comply with these new requirements the processing technology had to change. X-ray film requirements moved from 4084 square inches of film to 14,000 square inches. On similar castings Hot Isostatic Pressing (HIP) was introduced to improve part internal quality. Dimensional quality was improved with better process control, the incorporation of target machining and coordinate measuring machines.

After more than 20 years as the work-horse alloy of large structural castings IN-718 is being gradually replaced. Higher engine operating temperatures are necessitating the introduction of alloys such as Rene 220C, C263, IN-939, and MM509. PCC has several programs in place to evaluate the castability, weldability and mechanical properties of these alloys.

Superalloys 1988 Edited by S. Reichman, D.N. Duhl, G. Maurer, S. Antolovich and C. Lund The Metallurgical Society, 1988

## HISTORY OF CAST INCO 718

PCC entered the Large Structural Casting business for aircraft engines in 1965. Large castings were 24" diameter with a ship weight of 50 pounds. The primary alloy was INCO 718. The general requirements were:

Tolerances: ± .005 "/"

Wall Thickness: .100 minimum with  $\pm$  .025 tolerance

X-Ray Quality: Shrink-plate 4; gas-plate 5 Penetrant Quality: .030 Non-INterpretable

.060 Acceptable

Internal Quality: No limits.

The aircraft engine design engineers used this criteria in their designs for the next 15 years. The cost effectiveness and the design freedom of structural castings out-weighed any associated quality or weight penalties. INCO 718 allowed the Designers to increase the aircraft engine operating temperatures from the 400 alloy series of 900  $^{\circ}\mathrm{F}$  to the 1200  $^{\circ}\mathrm{F}$  range.

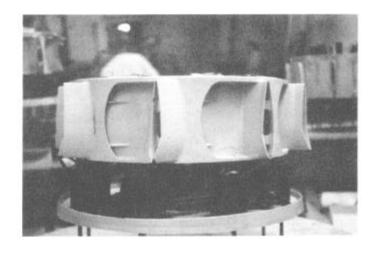


FIGURE I

TYPICAL LARGE CASTING

1960's era actual example 28" dia. ± .080 wall thickness .050/

8 strut stand-ups .030R

In the late 1970's the size of large casting more than doubled and the quality requirements were increased. They typical casting may weigh as much as 350 pounds and be 50 inches or more in diameter. The general requirements are:

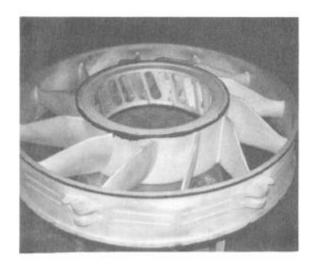
Tolerances: ± .003 "/" To Datums
Wall Thickness: .050 Minimum with ± .015
X-Ray Quality: Shrink-plate 1 or less; gas-plate 3
Penetrant Quality: .015 Non-Interpretable
.030 Rejectable
Internal Quality: Equal to the surface requirements

These new Quality requirements were incorporated at the same time as the inspection frequency and coverage was increased. Initially 3 castings were fabricated into a frame that today is cast as one piece. The initial three castings required a total of 4084 square inches of x-ray film. The current one piece casting requires over 14,000 square inches of film.

In order to comply with these new requirements the processing technology had to change. Hot Isostatic Pressing (HIP) was added to the process. This operation did improve quality but not to the degree required by the engine manufacturers. It was also determined that H.I.P. reduces the weldability of INCO 718, particularly in heavier sections. The welding problems associated with HIPped 718 were heat affected zone (HAZ) cracks and outgassing occurred because Argon was forced into such minute voids as non detected porosity and concentrations of Laves during the HIP cycle. There were several corrective actions implemented but the most cost effective was to improve the as cast skin, reduce the Laves concentrations and lower the HIP temperature.

The processes implemented to improve the HIP ability of cast INCO 718 had a minimum impact on eliminating the H.A.Z. cracks. Several process improvements, such as extended pre-HIP anneals, chemistry control and welder techniques reduced the HAZ cracks but the most consistent, cost effective method is to restrict post HIP welding. PCC has a vast amount of data which illustrates that HIP is very effective in eliminating all weld associated cracking.

Several process innovations and improvements have been incorporated to enhance the HIPability of INCO 718. The challenge was to improve the process and resulting quality without significantly increasing the costs. These process innovations and more rigid controls did improve the NDT quality to the degree the customer required.



TYPICAL LARGE CASTING 1980'S ERA

The new dimensional quality requirements were addressed with better controls and the incorporation of target machining. The dimensional quality of large structural castings has always been good but the methods and tools to confirm this on a part by part basis was not available, at least in a cost effective method. Small cast hardware types of fixtures were not effective tools to measure large structures and they were very expensive. Coordinate Measuring Machines in conjunction with targeting machines, both computer controlled, are very effective tools for dimensional control with a permanent record of the selected dimensions. The human element has been removed from the part by part dimensioning of large structural production castings.

After more than 20 years as the work horse alloy of large structural castings, INCO 718 is being gradually replaced. The new large generation aircraft engines are being designed to operate at temperatures higher than 1200°F. Most of the high temperature resistant alloys are non weldable which makes their ease of use difficult. These alloys include Rene 220, C263, IN-939, and MM509. PCC has several programs in place to test these alloys in structural castings. Tests include castability, weldability, mechanical properties and gating.

The results of current studies show these alloys to have fair to good castability when compared against each other and IN718 using standardized castability specimen. Fill and shrink behavior are good, based on the same specimen. However, standardized hot tear specimen data shows a wide range of results. C263 is the least prone to hot tearing followed by IN718, Rene 220C, MM509 with IN939 being very hot tear prone.

Mechanical property data of cast and heat treated specimen compared to wrought heat treated specimen varies. Alloys C263 and IN939 were similar in that, room temperature ultimate strengths were higher for the cast specimen compared to wrought specimen. Yield strengths were similar. Data from  $1450\,^{\circ}\text{F}$  tensile test showed similar trends. Mechanical property data for cast MM509 was similar to wrought data from literature. Wrought alloy Rene 220C mechanical property data is not available for comparison to cast data.

In terms of weldability, C263 and Rene 220C are as workable as IN718. However, IN939 and MM509 are difficult to weld. The reason appears to be either carbide or secondary phase precipitation in the matrix and grain boundaries due to either solidification time or section thickness. It is suspected that the metallurgical factors contributing to the hot tear property of these two alloys also contribute to their weldability behavior. In order to address the latter problem, structural castings made from these two alloys must be either made defect free, defect tolerant, or subject to repair techniques other than welding.

## SUMMARY

To summarize PCC's position on the use of high temperature resistant alloy applications in structural investment castings:

Producing complex shapes in these alloys appears possible as long as good foundry practice, gating techniques, and chemistry control are used. Casting mechanical properties can be expected to be good. Casting defect repair can be a problem and more work in this area needs to be done.

The long range outlook for large structural castings indicate that the major changes will be in thinner walls, (as low as .020) better profile tolerances (approaching  $\pm$  .001 "/" in the "new" structural alloys.