The Effect of Master Heat Alloy Variations on Porosity Levels in Investment Cast Rene 125 Alloy

PURDUE MATERIALS ENGINEERING

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April 20, 2010

Last stage solidification is largely determined by the solidification path. Minor alloying additions intended to increase creep resistance through the formation of carbides can alter the solidification path. Large precipitates and blocky carbides have the ability to hinder liquid flow in the interdendritic regions resulting in microporosity. In order to understand how minor alloy chemistry fluctuations and revert levels affect porosity, historical non-destructive test data was analyzed. Elements affecting porosity were identified and compositional changes were suggested. A master heat was melted using this recommendation and airfoils were cast. The resulting microstructure was compared with prior heats containing microporosity and shown to have less porosity.

Precision Castparts Corp.

This work is sponsored by Precision Castparts Corp. Airfoils Division Minerva, OH

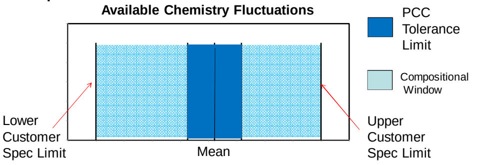
Project Background

The Rene 125 nickel-based superalloy is used by Precision Castparts Corporation in investment casting of equiaxed turbine airfoils. The investment casting process results in scrap metal, also known as revert, which comes from the gates, runners, and sprues. The revert is re-melted into future master heats for cost savings. However, using more revert material has been shown to cause higher microporosity, which results in a lower yield. The goal for this project is to recommend compositional changes to minimize the occurrence of porosity, while maintaining high revert usage.

Rene 125 Nominal Superalloy Composition (wt. %)

Ni	Cr	Co	Mo	W	Ta	Al	Ti	C	B	Zr
Bal	9.0	10.0	2.0	7.0	3.8	4.8	2.5	0.11	0.017	0.05

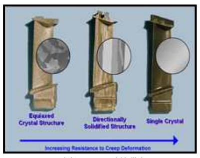
PCC maintains elemental composition tolerances tighter than their customers require.



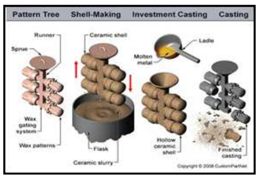
Specific compositional recommendations made to PCC are proprietary and are not disclosed.

Superalloys

Increasing demands for higher engine performance and better fuel efficiency has driven the advance of materials and their processing. Airfoils must resist any change in shape at high temperatures and therefore are unable to be forged. Investment casting is the production method of choice.



www.doitpoms.ac.uk/tlplib/creep



http://www.custompartnet.com/

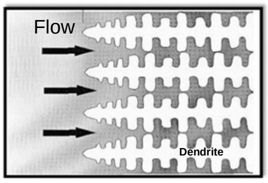
There are three possible types of microstructures in superalloys: equiaxed, directionally solidified, and single crystal. Engineers can control the microstructure through orientation, pour speed, thermal gradients, and chemistry. The Rene 125 chemistry for this project has been designed for the equiaxed microstructure. However, further optimization is needed because microporosity can still occur.

Permeability and Shrinkage

The low permeability of the interdendritic regions during the last stages of solidification is responsible for microporosity. Liquid metal flow is a result of solidification shrinkage and gravity. Fluid flow through a porous dendritic structure, can be described by Darcy's Law(Eq.1). Permeability(κ) is the ability of a porous material to transmit fluids(Eq.2). During solidification the liquid fraction(f_l) decreases as the specific area(σ) of the solidification front increases. An excessive drop in pressure leads to porosity.[1]

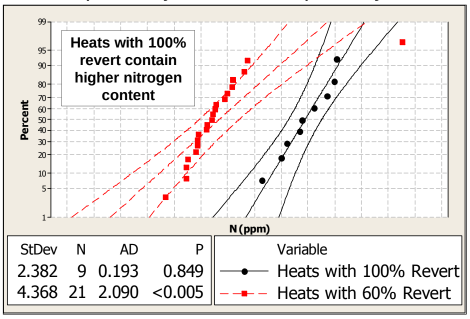
$$Q = \frac{K \cdot A}{\mu} \cdot \frac{\Delta P}{L} \qquad (1)$$

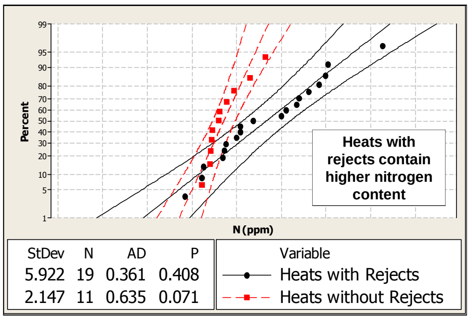
$$K \sim \frac{f_l^3}{\sigma^2} \qquad (2)$$



Statistical Analysis

The probability plots below show the nitrogen content in heats with 60% and 100% revert as well as heats with and without parts rejected due to porosity.

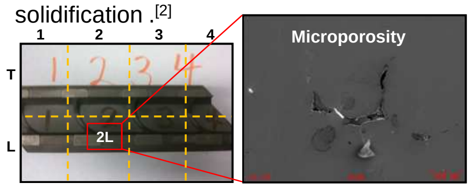




Creating probability plots for all elements quantified the separation of data which isolated and identified the constituents that could play a major role in porosity formation. Low Anderson-Darling(AD) coefficients indicate a stronger fit to a normal distribution. High P-values represent a higher accuracy of the reported mean values.[3,4]

Microstructure

Precipitates are present in the form of gamma-prime, carbides, nitrides and borides. These precipitates are of interest in equiaxed crystal structures because they greatly influence the permeability during solidification .[2]

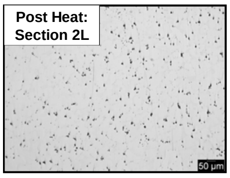


Base of a sample airfoil with observed microporosity through X-ray analysis.

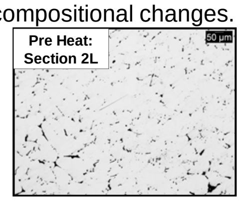
SEM micrograph showing microporosity.

Recommendations

Statistical analysis identified certain elements which had a beneficial effect on microporosity. Airfoils were cast from a master heat created using these recommendations. Micrographs were compared to evaluate porosity and precipitate differences between the heats with and without the compositional changes.



Micrograph showing smaller precipitates after recommended compositional changes.



Micrograph showing large precipitates before recommended compositional changes.

Comparison of Area Fraction of Precipitates in Pre- and Post-Recommended Airfoil Compositions*

	Post-Recommendation			Pre-Recommendation		
Section	2L	4L	4S**	2L	4L	4S**
Maximum	1429	412	227	7893	983	793
Average	157	43	43	217	153	49
Median	63	33	31	86	113	34
Std Dev	206	35	36	403	130	58

*Units are based on pixel counts from PAXit software analysis.
**Transverse cross-section

Conclusions

Micrographs from the post-recommendation heat show the average precipitate size to be smaller than the same sections of the pre-recommendation heat containing microporosity. The smaller precipitates reduce the probability of microporosity due to the increased permeability of the fluid flow in interdendritic regions.

References

[1] Santos, R.G. and Melo, M.L.N.M, "Permeability of interdendritic channels", *Materials Science and Engineering A,* Vol. 391, 2004.
[2] Whitesell, H S and Overfelt, R A, "Influence of solidification variables on the microstructure,macrosegregation, and porosity of directionally solidified Mar-M247", *Materials Science and Engineering A,* Vol. 318, pp. 264-276, 2001.
[3] Montgomery, Douglas C, Runger, George C and Hubele, Norma faris, *Engineering Statistics,* John Wiley & Sons, Inc, 2006.
[4] Minitab Inc. *Minitab 15.1.0.0.* [Software] s.l. Minitab Inc., 2006.