Shorter Aging Treatment for Cast Nickel-Based Superalloys

Students: Timothy Cummings, Joseph Meyer, John Smith
Faculty Advisors: Professor Kevin Trumble
Industrial Sponsors: Alcoa Howmet Castings

Alcoa-Howmet is working to reduce its heat treatment time of nickel superalloy turbine wheels from 20 hours to less than 10 hours. The current heat treatment is a bottleneck in production. A reduction in aging time would alleviate the issue. By studying gradient bars cooled at different rates and aged for 8 and 16 hours, a new heat treatment was designed by comparing the hardness and microstructures of the gradient bars to samples currently aged at 20 hours. The new heat treatment cycle has cut the aging time to 8 hours by changing the cooling rate after solutionization and aging temperature.

This work is sponsored by Alcoa Howmet Castings, Whitehall, MI & Laporte, IN

Alcoa Howmet

ALCOA

Project Background

Nickel-based superalloys are the primary material used in the hot section of almost all modern jet engines and industrial gas turbines due to their high temperature mechanical properties.

Heat treatment is done on these turbines to form microstructures with high temperature resistance to creep, corrosion, and fatigue.

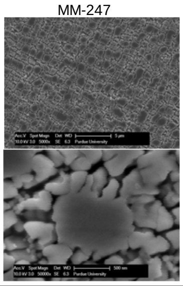
Industry Need: A production bottleneck occurs during the current aging cycle. Therefore, the aging cycle time needs to be reduced.
Goal: Develop a process that achieves equivalent microstructure and mechanical properties of current Alcoa-Howmet production alloys with an aging time of 10 hours or less.
Objectives: To develop an understanding of how the heat treatment parameters (time, temperature, and cooling rate) affect alloy microstructure. To then optimize parameters, achieving a shorter aging cycle with mechanical properties equivalent to current Alcoa-Howmet process.
Constraints: The mechanical properties of alloys must meet current specifications for stress rupture, creep resistance, and tensile strength.

Current Heat Treatment Cycles

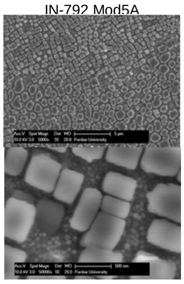
MM-247		Material	IN-792 Mod5A	
Temp (ºC)	Time (hr)	Cycle	Temp (ºC)	Time (hr)
1185	4	HIPing (172MPa)	1185	4
1185	2	Solutionization	1121	2
-	-	Cooling (not given)	-	-
871	20	Aging	843 760	4 16

Below are micrographs of the MM-247 and IN-792 Mod5A that have been heat treated by current production standards.

MM-247



IN-792 Mod5A



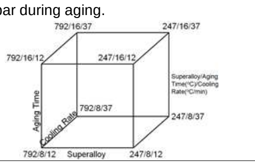
Experimental Procedure

Exploring Cooling Rate Effects

Cooling rate trials examined the effects the cooling after solutionization has on the microstructure. Four 1 cm cubes were cut from pre-HIPed turbine wheels for both IN-792 Mod5A and MM-247. Three cubes of each superalloy were solutionized. One cube of each was cooled at 12ºC/min, 37ºC/min and water quenched. The fourth pair of cubes were help as controls. All eight cubes were etched for high resolution Scanning Electron Microscopy (SEM).

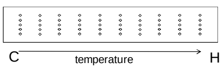
Gradient Aging

Sample turbine wheels were heat treated using the test matrix to create eight different gradient bars. Bars cut from each wheel were aged in a gradient furnace. Nine thermocouples were welded to the gradient bars to measure temperature in each section of the gradient bar during aging.



Gradient Testing

Vickers microhardness testing was done on all gradient bars. Five tests were performed at each 1 cm increment along the gradient bars. The diagram below shows frequency and orientation of the hardness tests.



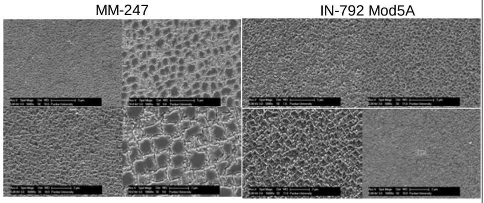
Scanning Electron Microscopy (SEM) was used to examine the microstructure of the superalloys. The SEM microscopy of each gradient bar was performed in line with hardness tests at each temperature to compare the microstructure of aging temperature.

Results

Cooling Rate Experiment

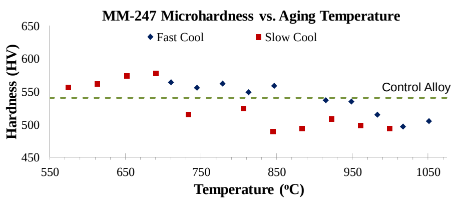
The Micrographs below show the comparison of the microstructures of MM-247 and IN-792 MOD5A after being fast cooled at 37ºC/min (left) and slow cooled at 12ºC/min (right). The cooling rate is done after solutionization.

MM-247 IN-792 Mod5A



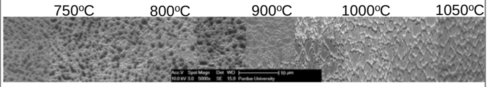
A plot of microhardness versus temperature was used to show which aging temperatures gives hardness close to or above the current alloys. Below are graphs of MM-247 and IN-792 Mod5A gradient bars which have been aged for 8 hours.

Gradient Aging Data MM-247



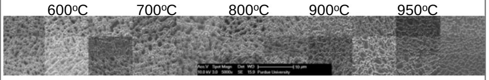
MM-247 Fast Cooled (37ºC/min) and aged from 710-1050ºC for 8 hrs

750ºC 800ºC 900ºC 1000ºC 1050ºC

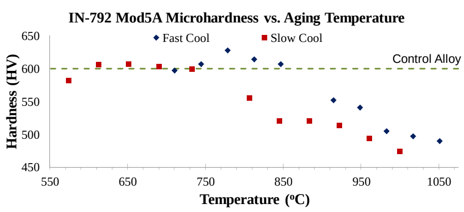


MM-247 Slow Cooled (12ºC/min) and aged from 575-1000ºC for 8 hrs

600ºC 700ºC 800ºC 900ºC 950ºC

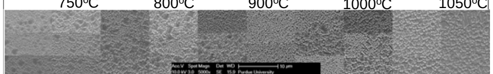


Gradient Aging Data IN-792 Mod5A



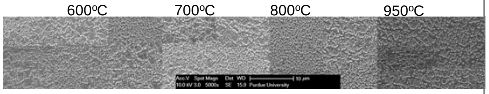
IN-792 Mod5A Fast Cooled (37ºC/min) and aged from 710-1050ºC for 8 hrs

750ºC 800ºC 900ºC 1000ºC 1050ºC



IN-792 Mod5A Slow Cooled (12ºC/min) and aged from 575-1000ºC for 8 hrs

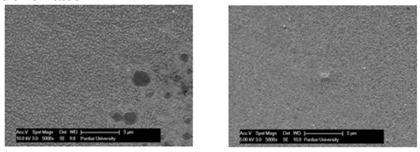
600ºC 700ºC 800ºC 950ºC



Analysis

Cooling Rate Discussion

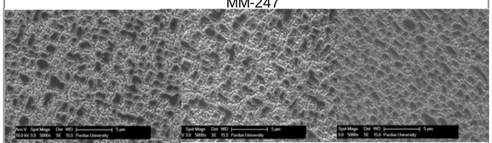
Micrographs from the cooling test shows a clear difference in precipitate size for MM-247 and IN-792 Mod5A. The slower the cooling rate after solutionization was, the larger the precipitates grew. An extra sample of each superalloy was water quenched to show the microstructure of MM-127 (left) and IN-792 Mod5A (right) just after solutionization and seconds to precipitate. Neither superalloy was fully solutionized in the 2 hour cycle due to segregation effects. However, the precipitates of both MM-247 and IN-792 Mod5A are significantly smaller in the quenched samples than those which have been cooled at slower rates.



Gradient Analysis

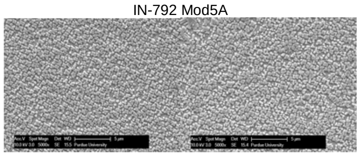
Only alloys that exhibited hardness greater than or equal to the current alloys were considered. Micrographs of the reference alloys were compared to the remaining images of each gradient bar for morphology, size and amount of fine γ'. Based on those two criteria, more segments of the gradient bar were eliminated from consideration. Using this analysis technique, we were able to determine the cooling rates for each superalloy and a small range of temperatures for aging. The mean of the ranges were chosen for the new aging temperatures.

MM-247



Temperature range 710-780 ºC

IN-792 Mod5A

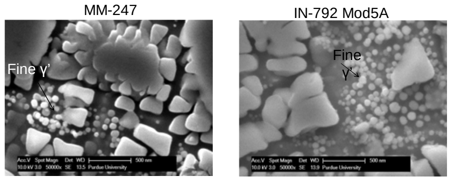


Temperature range 690-732 ºC

Range of temperatures in the gradient bars that exhibit similar microstructures and hardness to the current alloys.

To confirm the fine γ' is present due to heat treatment, micrographs were taken at increased magnification.

MM-247 IN-792 Mod5A



Fine γ' is able to precipitate at the temperature within the chosen ranges.

Testing will be performed on the superalloys that have been heat treated according to the new cycle recommended. Tensile testing will be performed at room temperature as well as 538ºC. Creep rupture testing will also be performed at both high and low temperatures.

Recommendations

MM-247 should be fast cooled and IN-792 Mod5A should be slow cooled. The aging time for both should be reduced from 20 hours to 8 hours. MM-247 should be aged at 750°C and IN-792 Mod5A should be aged at 725°C.

Future studies should be done on the cooling rate after solutionization since it showed it has a large effect on the microstructure of the superalloys.