Homogenization Optimization of Haynes® 242® Alloy

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Haynes international is looking for a more effective homogenization treatment for a 22" diameter ingot of Haynes® 242® that is triple melted by Electric Arc Furnace (EAF) and Argon Oxygen Decarburization (AOD), Electroslag Remelting (ESR), and Vacuum Arc Remelting (VAR). Since the inner radius is the last portion of the rod that would homogenize, a focus was placed on minimizing microsegregation there. Using the standard ramp up time for the Haynes furnace and hold times of 5 hours, 8 hours, 10 hours,15 hours, and 20 hours homogenization treatments were performed to observe the percent composition difference of the primary elements. A homogenized sample was received from Haynes International using their standard practice and one was performed based on the ThermoCalc model that had a hold time of 31 hours. ThermoCalc was used throughout to provide predictions of how heat treatments would perform, to determine an incipient melting temperature, and to minimize the microsegregation. It was observed that with greater hold times, the microsegregation of the sample decreased.

This work is sponsored by Haynes International, Kokomo, IN

Background

Goal: To create a homogenizing heat treatment for a triple melted 22" ingot of the Haynes® 242® alloy that minimizes microsegregation and time.

Table 1. Nominal Composition of the Haynes® 242® alloy [1].

Element	Weight Percent
Nickel	Balance
Molybdenum	25
Chromium	8
Iron	2 max
Cobalt	1 max
Manganese	0.8 max
Silicon	0.8 max
Aluminum	0.5 max
Carbon	0.03 max
Boron	0.006 max

Background: This process of triple melting an alloy involves Electric Arc Furnace (EAF) and Argon Oxygen Decarburization (AOD), electro-slag refining (ESR), and vacuum arc remelting (VAR). These processes (1) remove trace elements, (2) remove inclusions, and (3) creates a finer dendritic structure.

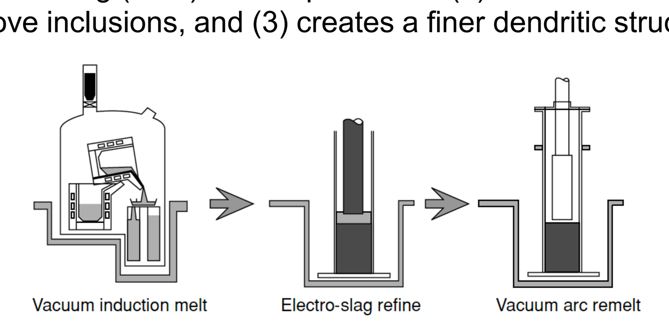


Figure 1. Schematic of the traditional triple melt process for superalloy ingots [2].

During the solidification of the ingot, dendrite arms are formed that spread from the mold wall. The thermodynamic properties of molybdenum causes it to segregate to the secondary dendrite interdendritic region, which causes microsegregation within the alloy.

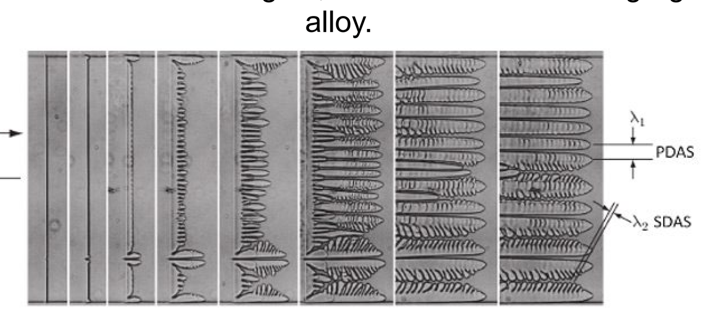


Figure 2. Example of dendritic growth within an ingot solidifying [3].

Experimental Procedure

Sample Preparation:

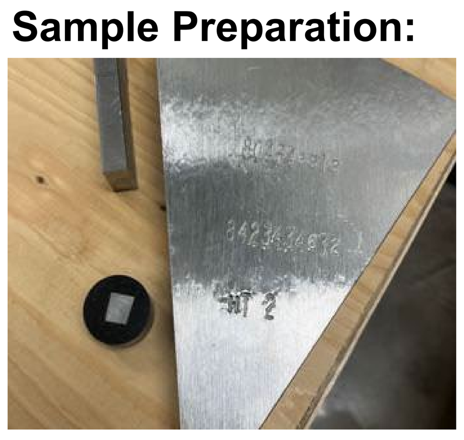
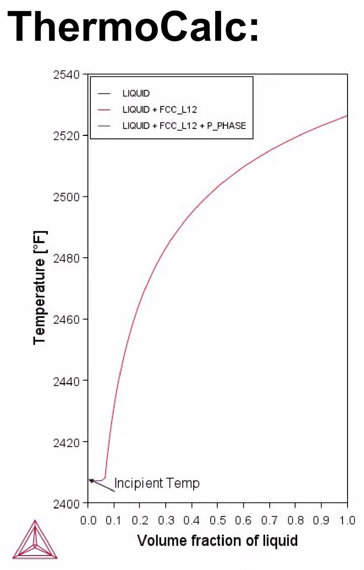


Figure 3. Section of 22" diameter Haynes® 242® ingot.

Samples of the inner, middle, and outer radius of a Haynes® 242® 22" diameter ingot were cut, polished to 1 µm, and observed using a Quanta 650 SEM to analyze microsegregation.

ThermoCalc:



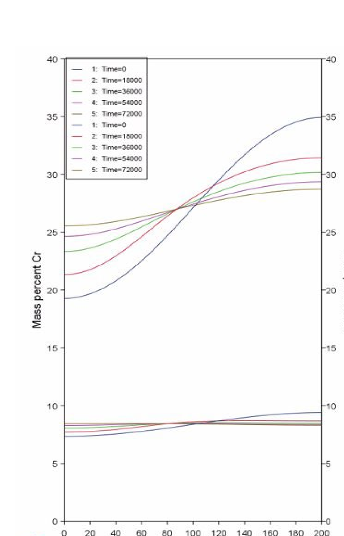


Figure 4 (left). Scheil simulation for non-equilibrium solidification showing Incipient melting temperature.

Figure 5 (right). ThermoCalc Diffusion Model used with inputs of secondary dendritic arm spacing and final composition from the Scheil Model to simulate heat treatments at different hold times.

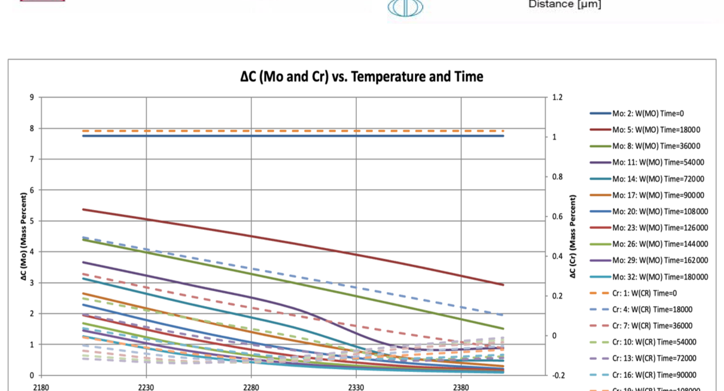


Figure 6. Plot of results from ThermoCalc isothermal diffusion simulation rearranged to show change in composition at temperatures for different hold times.

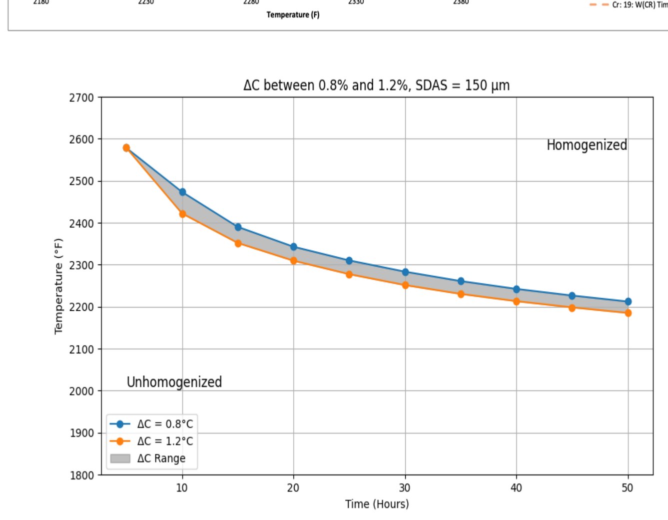


Figure 7. Example of Time Temperature plot produced from code that takes inputs of SDAS and target residual microsegregation to automate creation of heat treatment process.

Modeling of Heat Treatment

Below is the methodology behind the modeling of the heat treatment through mathematical and simulation means.

Heat Transfer:

$$t_{Tf-Ti} = \frac{R^2}{18\alpha}\left[1 - \frac{27}{10}ln\left(1 - \frac{((T_R - 3) - T_i)}{(T_R - T_i)}\right)\right]$$

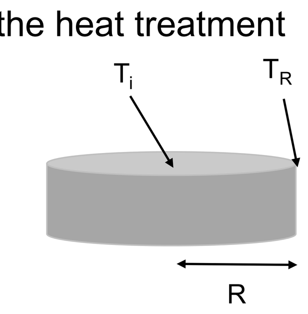


Figure 8. Equation and diagram of mathematical heat transfer model [4].

Table 2. Results of heat transfer model at varying temperature steps.

Temperature Range (K)	Time for Center to reach Second Temperature (hr)
298 - 1144	2.87
1144 – 1237	2.17
1237 – 1330	2.08
1330 – 1423	2.00
1423 - 1505	1.91

ThermoCalc:

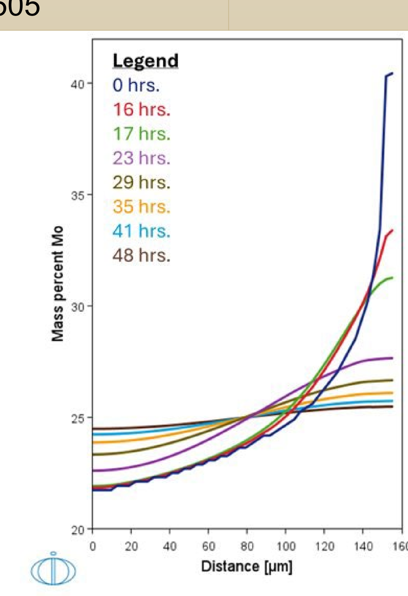


Figure 9. Plot of molybdenum composition (wt. %) vs. Distance (µm) at varying hold times.

Experimental Imaging

Below are the reported experimental images for the project. This gave information for (1) phases present, (2) incipient melting, and (3) secondary dendrite arm spacing.

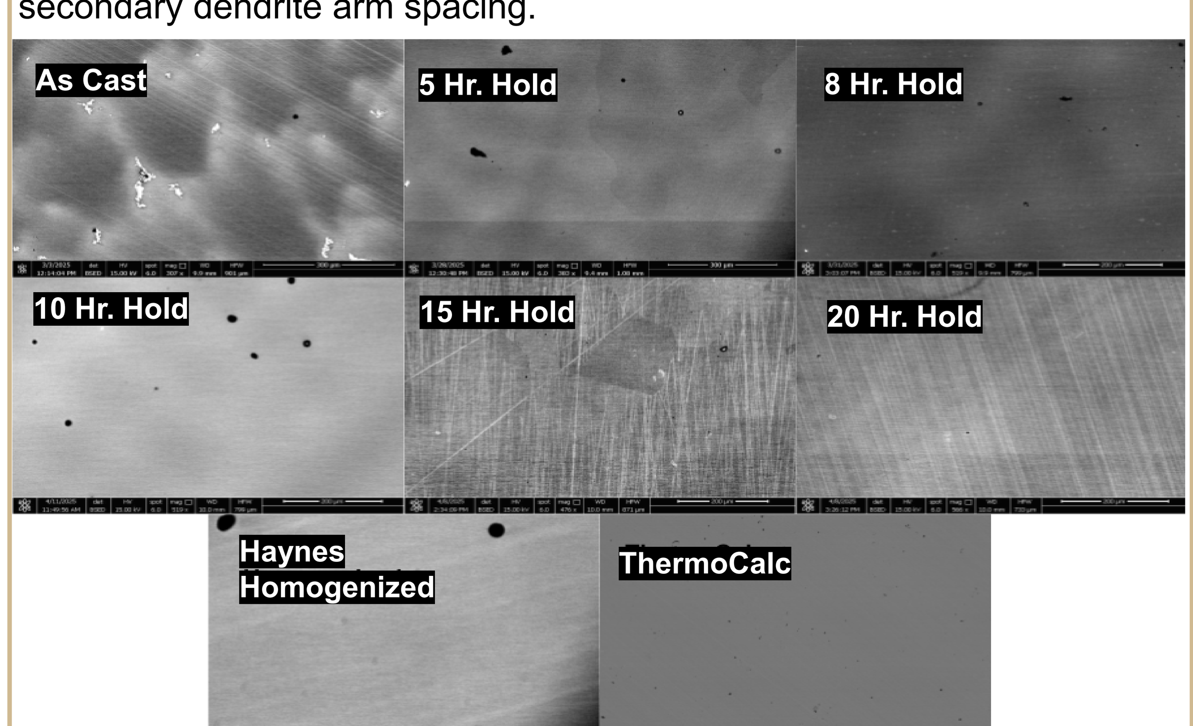


Figure 10. Backscatter SEM images of Haynes® 242® inner radius.

Brighter spots from backscatter are regions of high molybdenum content. It can be observed that microsegregation decreases with longer hold times.

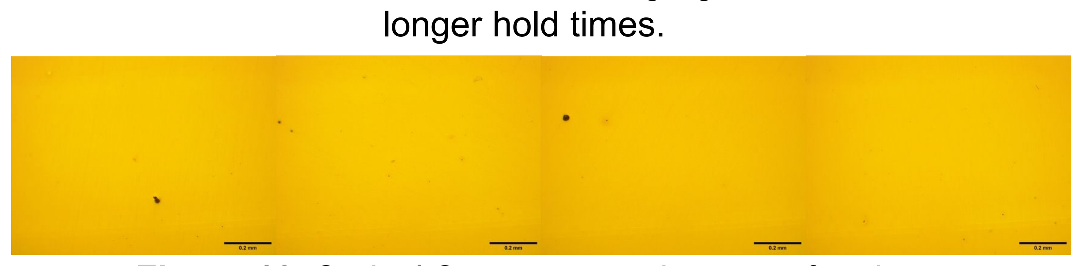


Figure 11. Optical Spectroscopy images of an inner radius sample held at 2250 °F for 6 hours to look for incipient melting.

Results: No incipient melting was observed

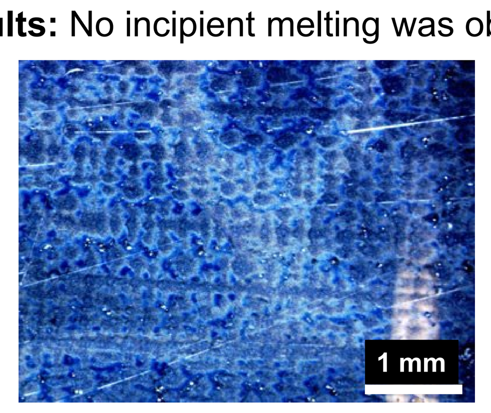


Figure 12. Scanning Electron Microscope (SEM) image of inner radius illustrating dendrite arms.

The SDAS is 155 µm, with standard deviations of 4.5 and 38.6 µm with the mid-radius and center of the alloy respectively.

Heat Treatment Results

Below are plots summarizing the microsegregation (utilizing the Flemings-Gungor approach [5]) within different samples: As Cast, Haynes Standard Practice Homogenized (HH), and ThermoCalc Simulation Homogenized (TC).

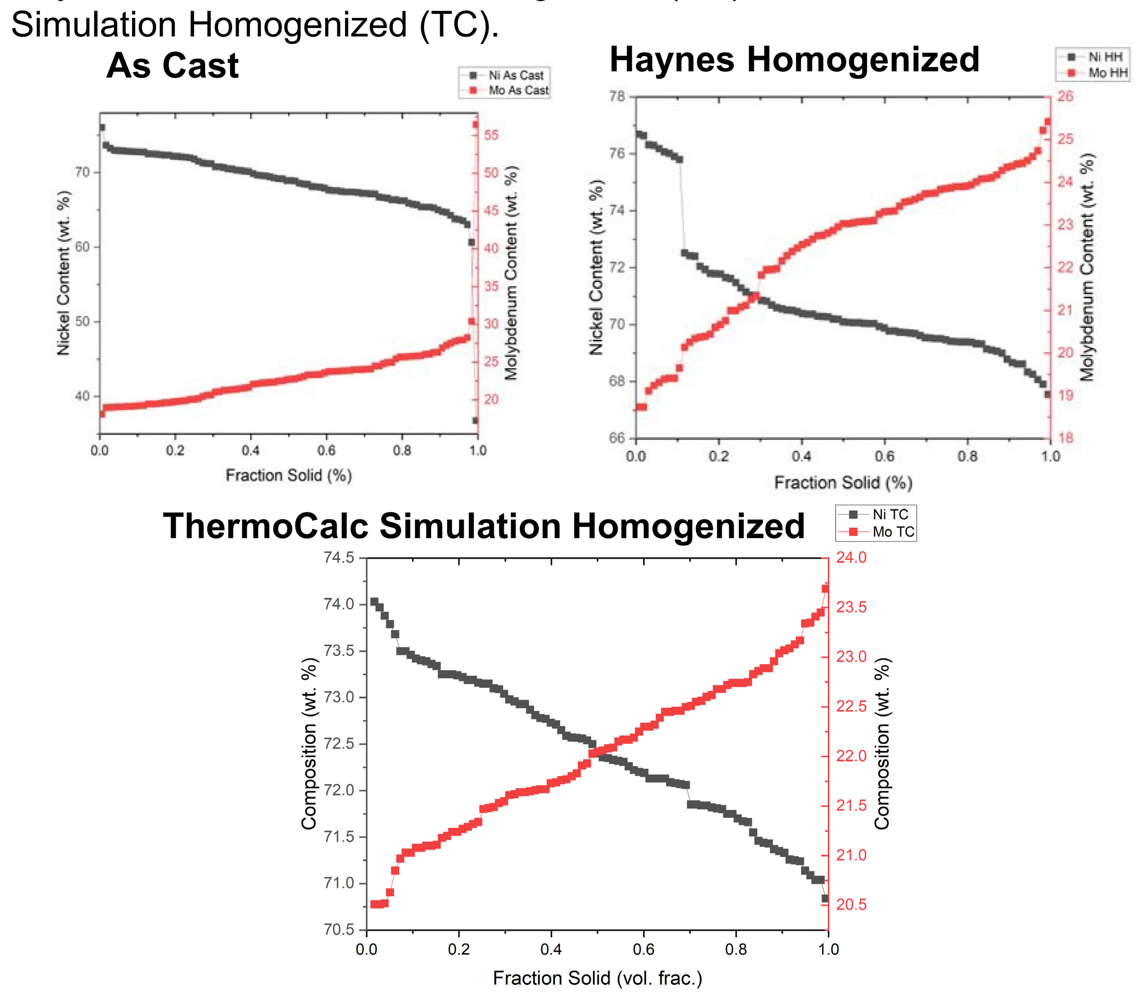


Figure 13. Plots of nickel and molybdenum composition (wt. %) vs. Fraction solid (vol. frac.) for various samples.

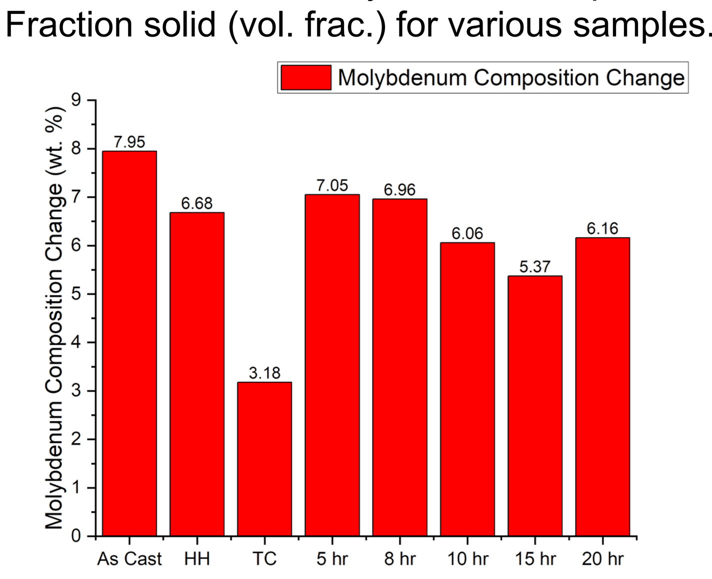


Figure 14. Molybdenum composition (wt. %) vs. Fraction solid (vol. frac.) for all tested samples.

Table 3. Comparison of ThermoCalc simulation values to experimental values.

Heat Treatment Sample Type	ThermoCalc Prediction of Molybdenum Composition Change (wt. %)	Experimental Results of Molybdenum Composition Change (wt. %)
As Cast	18.57	7.95
Haynes Homogenized	1.53	6.68
ThermoCalc Simulation Homogenized	0.97	3.18
5 hr Hold	5.41	7.05
8 hr. Hold	4.36	6.96
10 hr. Hold	3.81	6.06
15 hr. Hold	2.71	5.37
20 hr. Hold	1.94	6.16

Final Conclusions

To minimize time needed for the heat treatment, Haynes should consider an 18-hour hold heat treatment (15-hour hold + 3 hours for heat transfer). To minimize microsegregation, Haynes should consider a 34-hour hold treatment.

References

[1]: *Haynes® 242® alloy*. Haynes International. (2024a, August 6). https://haynesintl.com/en/datasheet/haynes-242-alloy/#nominal-composition
[2]: Reed, R. C. (2006). *The superalloys: Fundamentals and applications*. Cambridge University Press.
[3]: Dantzing, J. A., & Rappaz, M. (2009). *Solidification*. EPFL Press.
[4]: Gaskell, D., & Krane, M. J. M. (2012). *An Introduction to Transport Phenomena in Materials Engineering*. Momentum Press, LLC.
[5]: Ganesan, M., Dye, D., & Lee, P. D. (2005). A technique for characterizing microsegregation in multicomponent alloys and its application to single-crystal superalloy castings. *Metallurgical and Materials Transactions A*, *36*(8), 2191–2204. https://doi.org/10.1007/s11661-005-0338-2