Homogenization of Ni- and Co-based Superalloys

PURDUE UNIVERSITY

Materials Engineering

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The purpose of this project is to create an optimal homogenization heat treatment cycle for two designated alloys: HASTELLOY® B-3® and HAYNES® 188. Through experimentation the incipient melting range was discovered to be between 1270°C - 1320°C for both alloys. The secondary particles were optimally dissolved into solid solution at a heat treatment temperature of 1260℃ and at a hold time of 5 hours for both alloys.

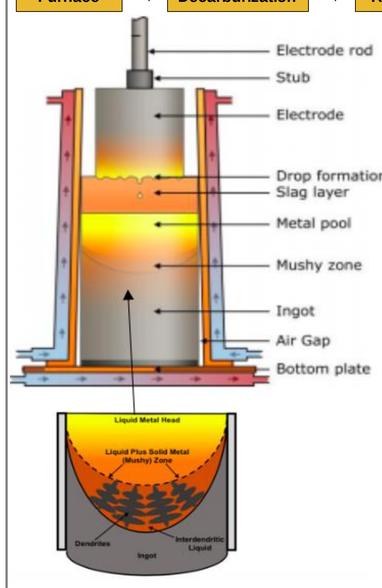
This work is sponsored by Haynes International, Kokomo, IN

HAYNES International

Project Background

Haynes International is a leading developer and manufacturer of nickel- and cobalt-based superalloys. The processing steps used are shown in Figure 1.

Electric Arc Furnace → Argon-Oxygen Decarburization → Electroslag Remelting → Homogenization Heat Treatment → Forging/ Rolling



Electro-slag remelting reduces impurities such as sulfur and phosphorous, but results in a solidified ingot with chemical inhomogeneities over micrometer and ingot length scales.

Carbides are formed due to non-equilibrium solidification and can be detrimental to the desired mechanical and corrosion properties.

Figure 1: Production flow chart and diagram of ESR [1]

Incipient melting occurs in interdendritic regions of lower localized solidus temperatures, and causes impaired mechanical properties due to accompanying expansion.

Microstructural Comparison

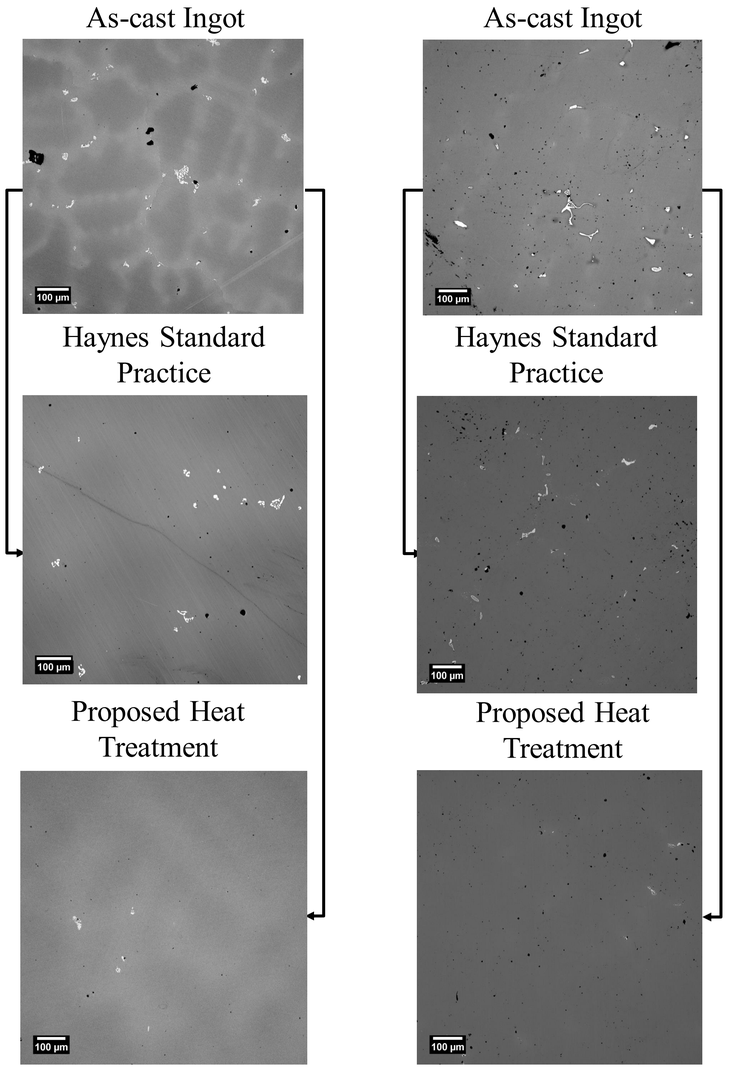


Figure 2: As-cast morphologies (top) with the Haynes' standard heat treatment (middle) and the team's proposed heat treatment of 1260°C for 5 hours (bottom)

References

(1) Radwitz, D.-I. S.; Scholz, D.-I. H.; Friedrich, H. C. B.; Franz, D.-I. H. *Influencing the Electroslag Remelting Process by Varying Fluorine Content of the Utilized Slag Proceedings of EMC 2015 1 Influencing the Electroslag Remelting Process by Varying Fluorine Content of the Utilized Slag*.

Incipient Melting

Tables 1&2: Experimental trials to establish incipient melting point

HASTELLOY® B-3®	
Incipient Melting	Sample Temperature
No	1230℃
No	1260℃
No	1270℃
Unclear	1320℃
Yes	1350℃
Yes	1380℃

HAYNES® 188	
Incipient Melting	Sample Temperature
No	1240℃
No	1260℃
Yes	1320℃

Incipient melting, as shown below in Figure 3, is seen at a temperature range between 1270°C - 1320°C for HAYNES® 188 and HASTELLOY® B-3®.

The incipient melting temperature of both alloys which exceeds the maximum temperature of Haynes International's furnace capabilities, 1260℃.

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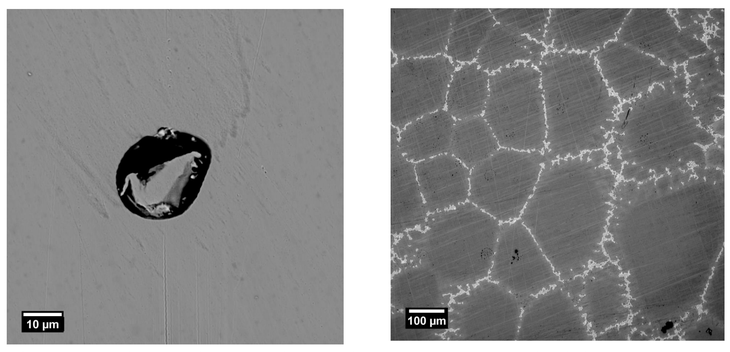

Figure 3: The left image shows the occurrence of incipient melting of HAYNES® 188 at 1320°C, and the right image shows incipient melting at 1380°C for HASTELLOY® B-3®.

Carbide Dissolution

Heat treatments were performed at 1260°C, for 3-24 hours for HASTELLOY® B-3® and 3-48 hours for HAYNES® 188.

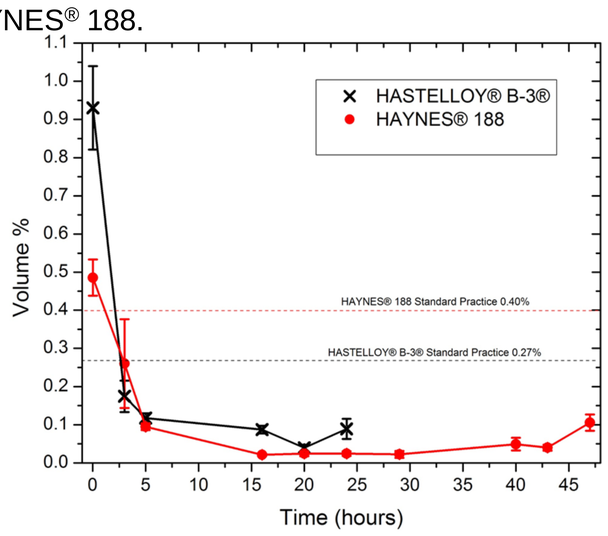

Figure 4: The plot shows the decrease in volume % carbide as a function of time. The dotted lines are the HSP results.

The heat treatment can be optimized by:
1) Minimizing the hold time to get equivalent carbide dissolution to the Haynes Standard Practice (HSP)
2) Maximizing carbide dissolution, past which carbide size and area fraction cannot be significantly minimized

Table 3: Experimental results detailing the effect of different heat treatments on carbide dissolution. The percentages represent reduction in cycle time from the Haynes standard practice (HSP).

	HASTELLOY® B-3®		HAYNES® 188	
	Volume % Carbides	Average Carbide Size	Volume % Carbides	Average Carbide Size
Equivalent to HSP	**2.5 hr** (84.37%)	**2 hr** (87.5%)	**1.2 hr** (85 %)	**3.5 hr** (56.25%)
Minimum Carbides	**5 hr** (68.75%)	**3 hr** (81.25%)	**16 hr** (+100%)	**29 hr** (+262.5%)
Proposed Heat Treat	**5 hr** (68.75%)	**3 hr** (81.25%)	**5 hr** (37.5%)	**5 hr** (37.5%)

Microsegregation

Microsegregation was quantified by measuring compositions over a randomly placed grid. Apparent solid fraction is determined by ranking of Co (HAYNES® 188) and Ni (HASTELLOY® B-3®).

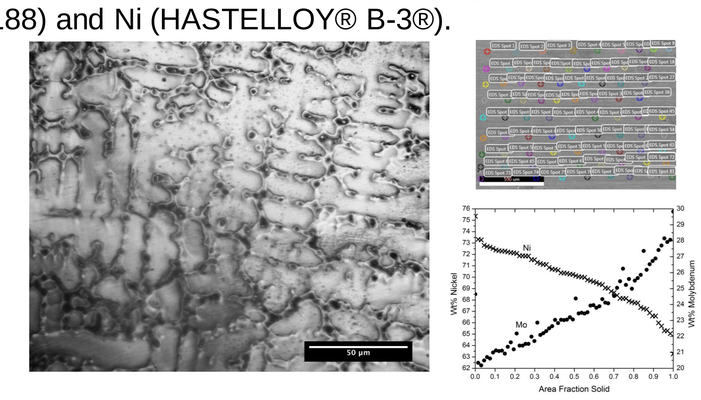

Figure 5: Identification of dendrites for microsegregation with corresponding point matrix EDS scan for HASTELLOY® B-3®

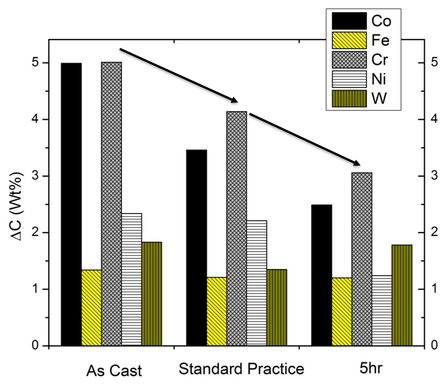

Figure 6: The graph shows the differences in elemental wt% between dendrite arms and interdendritic regions in HAYNES® 188 before and after heat treatment

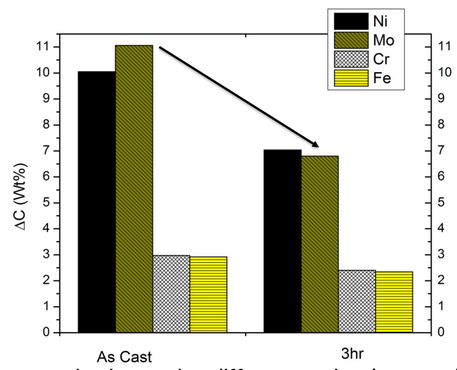

Figure 7: The graph shows the differences in elemental wt% between dendrite arms and interdendritic regions in HASTELLOY® B-3® before and after heat treatment

Recommendations

HASTELLOY® B-3® and HAYNES® 188:

The team recommends a 5 hour hold time at the Haynes furnace capability, 1260℃ to decrease hold time, and improve carbide dissolution.

Conclusions and Future Work

For the proposed heat treatment there is a potential 68.75% reduction in hold time for HASTELLOY® B-3® and 37.5% reduction for HAYNES® 188 as compared to the Haynes standard practice.

The proposed heat treatment has a 75% and 62.96% reduction in volume percentage carbides for HAYNES® 188 and HASTELLOY® B-3® respectively compared to the Haynes standard heat treatment.

For future work, the oxide formation on HASTELLOY® B-3® needs to be analyzed to determine the optimal heat treatment for this alloy without significant material loss. Additional microsegregation scans at various hold times could be used to determine the point past which the microsegregation could not be improved.