

As-Cast Microstructure of the Alloy 700 Nickel-Based Superalloys Fabricated Via Lost-Wax Casting

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Abstract: The presented research investigates Ni-based superalloy Alloy 700 castings produced via lost-wax casting. Casting analyses were carried out via thermodynamic simulations, differential scanning calorimetry (DSC), X-ray diffraction (XRD), light microscopy (LM), scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), scanning transmission electron microscopy (STEM), and tensile testing. The dendritic regions of the castings are characterized by a relatively homogenous microstructure, consisting of cubic-like γ' precipitates surrounded by the matrix. In the interdendritic spaces, $\gamma - \gamma'$ eutectic, MC carbides and M₃B₂, phases were identified.

Keywords: superalloy; Udimet 700; aerospace; investment casting

1 Introduction

Nickel-based superalloys are commonly used in highhomologous temperature applications due to their ability to maintain high strength and excellent resistance to hot corrosion and oxidation during long-term service ^[1-2]. The binary Ni-Al phase diagram includes various ordered phases characterized by high ordering enthalpy (e.g., NiAl, NiAl₃, Ni₂Al₃, NiAl₉, and the most important, Ni₃Al). The γ matrix of superalloys is strengthened by the coherent γ' phase, which possesses an ordered L1₂ structure ^[3]. Considering operation at high temperatures, the volume fraction, misfit, coarsening rate, and antiphase boundary energy (related to the chemical composition) of the γ' precipitates play an important role ^[4]. The ordering of the γ' phase depends on the strictly defined locations of Al and Ni atoms in its crystal lattice, which influences its behavior during high-temperature exposure and deformation. Ni₃Al is very rigid and impedes dislocation movement from the γ matrix, ensuring the required strength under service conditions^[5].

2 Experimental procedure

The lost-wax castings of Alloy 700 nickel-based superalloy were fabricated in vacuum condition. The nominal chemical composition is presented in Table 1.

Table 1. Composition of Udimet 700, wt%				
Cr	Со	Ti	Mo	Fe
15.0	18.5	3.4	5.0	<1.0
Al	C	В	Ni	-
4.3	0.07	3.4	Bal.	-

The as-cast specimens $(10 \times 10 \times 10 \text{ mm})$ were cut from the middle section of casting. For microscopic examinations, they were mounted in resin, ground, polished, and chemically etched in No. 17 reagent (25 mL H₂O, 25 mL HCL, 25 mL HNO₃, H₂MoO₄) for light microscopy (LM). LM images were captured by microscope Leica DM/LM. SEM observations were conducted using a Desktop XL instrument with a CeB6 electron source. The accelerating voltage during SEM-BSE (backscattered electrons) observations and X-ray energy dispersive spectroscopy (SEM-EDX) was 20 kV. The chemical compositions of primary precipitates were also measured by SEM-EDX. Quantitative chemical analysis was performed using the ZAF correction.

3 Result and discussion

The chemically etched specimens were analyzed via LM and revealed a typical dendritic structure (Figure 1). The dendritic areas (primary dendrites and secondary dendrite arms) are characterized by a relatively homogenous microstructure, while numerous eutectic $\gamma-\gamma'$ islands and carbide-looking precipitates are located in interdendritic spaces. The morphology of the secondary γ' precipitates resembles a cube (Fig. 2a). The deviation from the cubic shape occurs with increasing precipitate size. It should be noted that the morphology of γ' depends on the local thermodynamical conditions determined by the chemical composition, state of elastic stresses, and the mutual interaction between the precipitates [6-7]. These factors change as a function of temperature and are conditioned by the system's attempt to achieve thermodynamic equilibrium [8]. The morphology of the primary γ' precipitates is shown in Figure 2b. They were formed through the $L \rightarrow \gamma + \gamma'$ phase transformation. The amount of these precipitates is significant, which indicates a strong enrichment of the residual liquid phase in γ' -former. The precipitates are characterized by a diversified distribution and complex morphologies. Casting solidification is associated with

alloying element segregation, verified by the calculated partitioning coefficient values. This favors the formation of minor phase precipitates in close proximity to eutectic $\gamma - \gamma'$ islands.

b)

a)



Figure 1. Dendritic microstructure of the Ni-based superalloy: a-b) unetched sample; c-d) etched sample, LM



Figure 2. Morphology of the strengthening phases in the Alloy 700, Ni-based superalloy: a) secondary γ' precipitates in dendritic region; b) primary γ' precipitates and borides, SEM-BSE

The MC (enriched in Ti) carbides are characterized by complex morphologies, including blocks, sharp-edged parallelograms and Chinese script-like (feather-, herringbone-like). In the final stage of solidification, the eutectic reaction $L \rightarrow \gamma + \gamma'$ takes place in areas of Al- and Tienriched interdendritic liquid. As the solubility of B in γ and γ' is extremely low, it segregates into the boundary ($\gamma - \gamma'$) eutectic-residual liquid interface and provide favorable conditions for formation of borides (gray-contrasted precipitates).

4 Conclusions

This work focused on characterizing the as-cast microstructure and resulting properties of Ni-based superalloy Alloy 700, produced via lost-wax casting. The obtained results allowed to draw the following conclusions:

-Casting characterize by typical dendritic microstructure with irregular distribution of strengthening phases.

-Secondary γ' precipitates posses a cubic-like morphology and volume fraction above 40%.

-In the close vicinity of eutectic $\gamma - \gamma'$ islands, MC carbides and borides were detected.

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