

Microsegregation and Rayleigh number variation during the solidification of superalloy Inconel 718

Ling Wang^{1,2)}, Jianxin Dong¹⁾, Yuliang Tian¹⁾, and Lei Zhang²⁾

1) School of Materials Science and Engineering, University of Science and Technology Beijing, Beijing 100083, China

2) College of Mathematics and Physics, Nanjing University of Information Science and Technology, Nanjing 210044, China

(Received 2007-10-19)

Abstract: The microstructure and composition of the residual liquid at different temperatures were investigated by scanning electron microscopy (SEM) and energy dispersive X-ray spectrometer (EDX) associated with the Thermo-calc software calculation of the equilibrium phase diagrams of Inconel 718 and segregated liquid. The liquid density difference and Rayleigh number variation during solidification were estimated as well. It is found that the heavy segregation of Nb in liquid prompts the precipitation of δ and Laves phase directly from liquid and the resultant quenched liquid microstructure consists of pro-eutectic γ +eutectic, or complete eutectic according to the content of Nb from low to high. The liquid density increases with decreasing temperature during the solidification of Inconel 718 and the liquid density difference is positive. The largest relative Rayleigh number occurs at 1320°C when the liquid fraction is about 40vol%.

© 2008 University of Science and Technology Beijing. All rights reserved.

Key words: superalloy Inconel 718; microsegregation; liquid density difference; Rayleigh number

1. Introduction

Inconel 718 is a Ni-Cr-Fe based superalloy whose main alloying elements are Nb, Mo, Ti, and Al. The alloy is strengthened by precipitates of γ' with the face centered A_3B type structure and body centered tetragonal γ'' . Because of its excellent properties at medium temperature, Inconel 718 has been found extensive applications in aerospace industry, nuclear power plants, and petrochemical engineering as well. However, Inconel 718 has high contents of Nb and Mo (5wt% Nb and 3wt% Mo) and is susceptible to heavy segregation and even macrodefects, such as freckles [1-9].

Freckle is a kind of macrosegregation with a diameter of more than 1 mm and it is difficult to eliminate by heat treatment and preprocessing. So the ingots with freckles are scrapped, which limits the scale-up of the size and development of superalloy castings [10-16]. According to the traditional freckling mechanism, freckles form by thermosolutal convection driven by the density difference between the lighter liquid at the dendrite bottom and the heavier liquid at the dendrite tips. Based on this theory, sev-

eral versions of freckle criteria were proposed. The criterion given by Flemings and co-workers was found to predict the freckle formation satisfactorily according to Ref. [9]. In this article, the liquid density and Rayleigh number were calculated by the method provided by Refs. [17-18] and the freckling tendency in Inconel 718 was analyzed.

2. Experimental

The chemical composition (wt%) of Inconel 718 is C 0.021, Nb 5.36, Ti 0.97, Al 0.56, Mo 2.98; Fe 19.93, Cr 17.72, and Ni balanced. The raw experimental materials were vacuum induction melted and vacuum arc remelted beforehand.

The remelting process in the experiment was designed according to the melting temperature range of Inconel 718 which was 1260-1336°C. All the samples are columns of $\phi 25$ mm $\times$ 35 mm. They were heated to 1400°C in alumina crucibles, held for 20 min for soaking and then cooled in the furnace to a temperature in freezing range; held for 20 min followed by quenching in water. The temperatures at which the samples were quenched were designed as 1360, 1340,

1320, 1300, 1280, 1260, 1240, 1200, 1180, and 1140 °C, respectively.

Oxidization scale on the remelt-treated samples was removed by the grinder. Then these samples were ground to 1000-grit followed by being mechanically polished and then electro etched in a solution of CrO_3 , H_2SO_4 , and H_3PO_4 at a voltage of 10 V for 10 s. The microstructure of these etched samples was investigated by an S250 scanning electron microscope (SEM). The composition of liquid, dendrites, and some phases in the microstructure at different temperatures was analyzed by EDX.

3. Results and discussion

3.1. Solidification microstructure and segregation

The SEM micrographs of some remelted samples are shown in Fig. 1. The alloy liquidus of Inconel 718 is below 1340°C and it is complete liquid in the microstructure of Fig. 1(a). Below 1340°C, the liquid transforms into solid quickly and it can be seen from Fig. 1(b) that there is less than 50vol% residual liquid in the microstructure at 1320°C. When the tempera-

ture decreases to 1280°C, the interdendritic liquid network becomes discontinuous (Fig. 1(c)). The residual liquid at 1180°C distributes as strips and short bars in the microstructure as shown in Fig. 1(d). There is about 5vol% liquid that remains in the microstructure quenched at 1180°C.

The composition variation in the interdendritic liquid was investigated. At least five times of measurements of the liquid composition at each temperature were made by EDX. The segregation of alloying elements during solidification is shown in Fig. 2(a). The liquid fraction is shown by the dash dotted line. It can be seen that the content of Nb increases quickly and greatly as solidification. There is about 16wt% Nb in the final liquid although there is only 5wt% Nb in the nominal composition. The increasing Nb content concentrates at a temperature above 1300°C when the liquid fraction decreases from 100vol% to less than 20vol%. The content of Mo and Ti in the liquid has a light increase during solidification. But the content of Fe and Cr significantly decreases in the residual liquid with decreasing temperature.

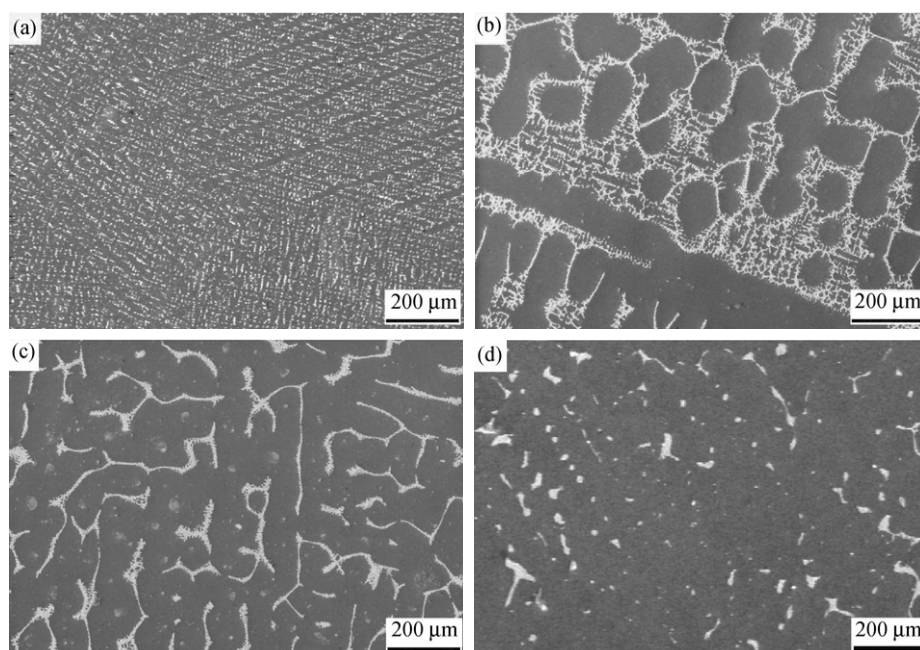


Fig. 1. Solidification microstructures at (a) 1340°C; (b) 1320°C; (c) 1280°C; (d) 1180°C.

To accurately and completely investigate the segregation behavior during the solidification of Inconel 718, the segregation ratios (SR) at different temperatures were calculated and the result is shown in Fig. 3(b). For the alloying elements of positive segregation, the higher the content of Nb in the interdendritic liquid, the higher the SR and the heavier the segregation. But for the alloying elements of negative segregation, the lower the SR, the less the depletion of the elements in the solid. Fig. 3(b) shows that the SR of Nb

increases greatly and quickly as the temperature changes from 1340 to 1300°C but the increase becomes slowly under 1300°C and the SR at 1180°C has a slight increase. The SR of other positive segregation alloying elements, such as Mo and Ti, has a similar change tendency during solidification but their value is much lower than that of Nb. The maximum SR of Nb reaches 5.5. The SR curves of negative segregation alloying elements, Cr and Fe, are very similar to each other and their value is lower than 1. The SR of Ni is

Download English Version:

<https://daneshyari.com/en/article/1630409>

Download Persian Version:

<https://daneshyari.com/article/1630409>

[Daneshyari.com](https://daneshyari.com)