EFFECT OF OXYGEN, NITROGEN AND MAGNESIUM ON SEGREGATION,

SOLIDIFICATION AND MECHANICAL PROPERTIES IN ALLOY 718

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Abstract

Supreme quality alloy 718 production requires to meet low contents of oxygen and nitrogen. The oxygen and nitrogen effects and microalloying of Mg at low level of oxygen and nitrogen have been studied in alloy 718. Oxygen and nitrogen increase the amount of Laves phase in cast ingots, however there are no distinguished influences on tensile and stress rupture properties of hot rolled alloy 718 bar specimens from homogenized ingots with contents of oxygen and nitrogen less than 20 and 50 ppm respectively. Magnesium still shows its beneficial effect on stress rupture life in alloy 718 with low contents of oxygen (< 10ppm) and nitrogen (< 20ppm). Interdendritic δ -Ni₃Nb can precipitate directly from the liquid and its formation mechanism should be investigated further.

Introduction

The role of Mg has been systematically studied not only in wrought [1] but also in cast [2] alloy 718. The beneficial effect of Mg has been confirmed and its application has been adopted in current production of alloy 718 [3]. Further development of supreme quality alloy 718 requires high cleanliness, such as alloy with very low content of oxygen and nitrogen.

Purpose of this paper is to study the influence of oxygen and nitrogen on segregation, solidification and mechanical properties of alloy 718 at the level lower than 20ppm oxygen and 50ppm nitrogen. The Mg effect has been also investigated at low level of oxygen (<10ppm) and nitrogen (<20ppm).

Materials and Experimental Procedure

Seven experimental heats of alloy 718 with variation of oxygen, nitrogen (Group A) and magnesium (Group B) were melted in 25Kg VIM furnace with CaO crucible and poured in 10Kg ingots.

Chemical composition and alloy designation are listed in Table 1. Heat LON in Group A is a base alloy 718 with low contents of oxygen (4ppm) and nitrogen(18ppm). Heat O2 and ON1, ON2 are alloys with higher content of oxygen(25ppm) and higher contents of oxygen(16ppm) together with nitrogen(29,47ppm). All the alloys in Group A were microalloyed with Mg(40–50ppm). Alloys M1, M2 and M3 were designed for variation of Mg from 40 to 160ppm at low contents of oxygen(<10ppm) and nitrogen (<20ppm).

Table1. Chemical Composition of Investigated Alloy 718(wt%)

Group	Heat	C	Cr	Mo	Fe	Nb	Ti	Al	B	Mg	O	N
A	LON	0.047	18.90	3.05	16.86	5.22	0.99	0.61	0.0036	0.0052	0.0004	0.0018
	O2	0.046	19.01	3.04	16.83	5.25	1.02	0.56	0.0034	0.0054	0.0025	0.0019
	ON1	0.031	18.81	3.00	17.05	5.24	1.02	0.60	0.0034	0.0043	0.0016	0.0029
	ON2	0.041	18.74	3.00	16.88	5.19	0.99	0.61	0.0033	0.0049	0.0016	0.0047
B	M1	0.035	18.77	3.00	16.81	5.29	0.97	0.60	0.0035	0.0040	0.0008	0.0016
	M2	0.050	18.93	3.01	16.87	5.31	1.00	0.56	0.0034	0.0091	0.0006	0.0019
	M3	0.046	18.81	3.02	16.79	5.19	0.99	0.57	0.0035	0.0160	0.0008	0.0019

* Ni—balance, Si<0.05%, Mn<0.03%

All ingots were conducted with 2 step homogenization treatment, i.e., 1160°C / 10h → 1180°C / 30h / FC. Seven ingots were forged down to 40mm square bars and finally hot rolled to Φ18mm bars for tensile tests at ambient temperature and 650°C. Stress rupture tests were conducted at 650°C and 686 Mpa. All experimental alloy bar

samples for mechanical testing were given the ASM 5596C heat treatment, i.e., 950°C / 1h / AC + 720°C / 8h / FC 50°C / h → 620°C / 8h / AC.

Cast structure analysis samples were directly cut from each ingot before homogenization.

Solidification study was carried out on the samples by means of melting and cooling and followed by metallographic analyses, i.e., samples were heated to 1420°C / 5min. for melting to get liquid phase then furnace cooled to a certain temperature for keeping 10 minutes and followed by water quenching for observation solidified structure at certain temperature and simultaneously to determine the finish temperature of solidification.

Structural characterization techniques were carried out by means of optical, SEM and TEM microscopy and selected diffraction on carbon extraction replica.

Experimental Results and Discussion

Fig.1 shows the cast structure of samples taken from the same location of 3 ingots with different contents of oxygen and nitrogen. Typical globular and eutectic Laves phase has formed in the interdendritic areas. However, heat LON alloy 718 with lowest contents of oxygen (4ppm) and nitrogen (18ppm) characterizes the least amount of Laves phase (Fig.1a). For alloy 718 with higher contents of oxygen and nitrogen, heat O2 with 25ppm O and 19ppm N, heat ON2 with 16ppm O and 47ppm N, more Laves phase appears in the interdendritic areas (Fig. 1b and c).

Solidification study on seven heats by heating and cooling method shows that oxygen, nitrogen and magnesium have no distinguished influence on start and finish temperatures of solidification, which are almost in the ranges of 1340–1350°C and 1100–1110°C respectively. Detail metallographic observation shows very often the existence of an "unknown" primary phase (its morphology is different to Laves phase) in co-existence with final solidified liquid, such as thick arrows A indicated in Fig.2a and b in heat ON1 specimen as an example.

Details of "unknown" primary phase have been shown at higher magnification under SEM (see Fig.3). Fig.3a and b show the co-existence of quenched liquid phase L and γ +Laves eutectic with the "unknown" primary phase. Careful observation indicates partial lamellar structure as the nuclei of the phase. Delta Ni_3Nb platelet formation direct at the phase (Fig.3b) reminds us trying to identify it as $\delta\text{-Ni}_3\text{Nb}$.

Table 2. Chemical Composition (wt.%) of Phases in Investigated Alloy 718 by Electron Probe

Phase	Ni	Ti	Nb	Fe	Mo	Cr
Laves Phase	40.74	0.96	29.68	10.91	4.08	13.37
"Unknown" Phase	63.14	1.71	26.18	3.74	0.85	4.21
Retained Liquid	48.35	1.42	23.55	9.98	2.87	12.92

Fig.1. Effect of oxygen and nitrogen on interdendritic segregation behaviour of alloy 718.

Heat LON——4ppm O, 18ppmN;

Heat O2——25ppm O, 19ppmN;

Heat ON2——16ppm O, 47ppmN.

Fig.2. "Unknown" interdendritic precipitated phase (as thick arrow A indicated) formed at almost finish solidification temperature 1100°C.

Fig.3. Details of "unknown" interdendritic precipitated phase (as thick arrow A indicated with co-existence of quenched liquid phase L (a) and γ +Laves eutectic (b)).

Table 2 shows results of micro-chemical analyses on Laves, "unknown" phase and retained liquid. Chemical composition of "unknown" phase is different to Laves phase and it is very rich in nickel (63.14%Ni) and niobium (26.18%Nb). Chemical analyses on electrolytic isolated δ -Ni₃Nb precipitated in wrought alloy 718 in literature [4] show as follows: 60.81%Ni, 3.66%Ti, 28.57%Nb, 2.67%Fe, 2.27%Mo, 1.91%Cr. It indicates that chemical composition of the "unknown" phase is very close to δ -Ni₃Nb. For further identification this "unknown" primary phase was extracted on carbon replica and confirmed by TEM selected diffraction as orthorhombic δ -Ni₃Nb phase (Fig4a and b).

Primary δ -Ni₃Nb phase can be also found in co-existence with γ +Laves eutectic in cast ingot as show in Fig.5 arrow A indicated. Primary δ -Ni₃Nb morphology is different to a blocky form of Laves phase (comparison in Fig 5b).

Our results show that severe segregation of Nb in alloy 718 is not only due to existance of Laves phase but also primary δ -Ni₃Nb formation. Because of relatively large amount of Laves phase the presence of primary δ -Ni₃Nb might be inobservant. Nevertheless, primary δ -Ni₃Nb formation mechanism and its behaviour should be investigated further, that might be as an important factor especially for cast alloy 718. However, segregated phases Laves and δ -Ni₃Nb are dissolved both in γ matrix after two step homogenization treatment on alloy ingots.

Grain sizes of hot rolled bar specimens after AMS 5596C heat treatment are in range of ASTM 10-12. Oxygen and nitrogen effects on tensile properties at ambient temperature and 650°C, and on 650°C stress rupture properties are shown in Fig.6a, b and C. In alloy 718 oxygen and nitrogen contents lower than 20 and 50ppm respectively almost have no distinguished effects on tensile properties at ambient temperature and 650°C, both (see Fig.6a and b). For those heats in Group A with variation of oxygen and nitrogen their stress rupture lives are longer than 100-200hrs at 650°C and 686Mpa. It indicates that oxygen and nitrogen do not show detrimental effect on stress rupture property. For further investigation of oxygen and nitrogen effects on mechanical properties in a wide range, cyclic stress rupture and LCF properties will be tested.

The results of Mg effect on mechanical properties for alloy 718 with low contents of oxygen (<10 ppm) and nitrogen (<20ppm) are concordant with the results in commercial alloy 718[1]. Mg does not show distinguished effect on tensile strengthes at ambient temperature and 650°C both. However, Mg does show beneficial effect on stress rupture life. Microalloying of Mg in alloy 718 with 50ppm or more shows longest stress rupture life at 650°C, 686 Mpa as shown in Fig.7.

Fig.4. Interdentritic precipitated phase as thick arrow A indicated in (a) and its electron diffraction pattern identified as δ -Ni₃Nb(b).

Fig.5. Typical morphology of δ -Ni₃Nb in co-existence with γ +Laves eutectic.

Fig.6. Influence of oxygen and nitrogen on tensile properties at ambient temperature (a) and 650°C (b), and on stress rupture properties at 650°C, 686 Mpa(c).

Fig.7. Magnesium effect on stress rupture life at 650°C, 686Mpa.

Conclusions

1. Oxygen and nitrogen have mild effect on segregation behaviour, the amount of Laves phase will be slightly increased with the increment of oxygen and nitrogen in alloy 718.
2. Severe segregation of Nb in alloy 718 as cast condition can be formed not only due to existence of Laves phase but also due to the formation of primary δ -Ni₃Nb. However, both Laves and δ -Ni₃Nb are dissolved in γ matrix after homogenization treatment.
3. Oxygen and nitrogen do not show distinguished effect on mechanical properties in alloy 718 with the oxygen and nitrogen in the range of less than 20ppm and 50ppm respectively.
4. Mg does show beneficial effect on stress rupture life in alloy 718 with low contents of oxygen (<10ppm) and nitrogen (<20ppm).

References

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