Materials Science and Engineering A 499 (2009) 215–220

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Alloy design and development of INCONEL718 type alloy

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ARTICLE INFO

Article history:
Received 1 June 2007
Received in revised form 3 September 2007
Accepted 13 November 2007

Keywords:
Alloy design
718 type alloy
Thermo-Calc
Precipitation behavior

ABSTRACT

The effect of alloying elements such as Al, Ti, Nb, W and Co in INCONEL 718 type alloys on phase precipitation behavior has been investigated by means of Thermo-Calc software. The results show that both the solvus temperature and fraction of phases in 718 type alloys has been significantly changed with variation these alloying elements. The experimental results also reveal that precipitation kinetics of δ, γ'' and γ' phases in developed 718 type alloys have been changed. The alloy with higher content of Al shows microstructural stability superior to that of conventional 718 alloy. Based on thermodynamical and experimental results, the optimum content of Al, Ti and Nb of the developed 718 type alloy without W and Co additions has been determined to be 1%, 1% and 5.5%, respectively.

1. Introduction

INCONEL 718 is a nickel-base superalloy strengthened mainly by Ni_3Nb type γ'' and partially by Ni_3Al type γ' precipitation. Since its invention in the 1960s, INCONEL 718 has found wide application in different high-temperature industries because of its unique mechanical properties and good workability. INCONEL 718 is still today's most widely used superalloy in the world [1]. However, it cannot be used at temperatures higher than 650 °C because of the instability of its main strengthening phase γ''.

In the past more than 20 years many researchers did a lot of work to improve the structure stability of INCONEL 718 at high temperatures and intended to develop a new 718 type alloy to be used beyond 650 °C [2–9]. One of the methods is to control γ'' and γ' phase precipitation behavior by means of adjustment of Al, Ti and Nb contents. The other idea is to strengthen the γ matrix by altering the content of solid solution elements such as W and Co. The adjustment of these alloying elements can change phase precipitation behavior. If detailed information dealing with phase precipitation behavior can be obtained before experimental work for alloy development, a lot of time can be saved and the development cost can also be reduced. In recent years, computer modeling based on experimental data plays an increasing role in alloy design and development.

This paper concentrates on the study of the effect of Al, Ti, Nb, W and Co on phase precipitation behavior via thermodynamic calculation to determine the optimum range of alloying elements in newly developed 718 type alloy. Based on thermodynamic calculation and experimental results, several modified 718 type alloys have been suggested and the newly developed 718 type alloys can be used beyond 650 °C.

2. Results of "Thermo-Calc" calculation

Thermodynamic calculations were performed on a variety of elements such as Al, Ti, Nb, W and Co via Thermo-Calc software and occasionally JmatPro software to study the effect of these alloying elements on phase precipitation behavior. All these calculations are based on the chemistry of conventional INCONEL718 alloy. Minor elements such as P, S and trace element Mg are not included because they are not available in current Thermo-Calc database.

Thermodynamic calculation results indicate that the effect of increasing Al shows a strong increase in γ' solvus (Fig. 1a) while δ phase solvus shows mildly decrease when Al level is less than 2%, after that it dramatically decreases (Fig. 1c). Laves phase precipitation and the appearance of σ phase are occurred when Al content reaches 2% (Fig. 3a and b). In fact, when Al content is beyond 1.5%, σ phase has already precipitated in a considerable scale. Fig. 2a shows the fraction of γ' increases greatly while the fraction of δ phase decreases remarkably with the increment of Al content (Fig. 2b).

With the increase of Ti content, the γ' solvus increases rapidly and reaches a maximum at 2% Ti and then decreases (Fig. 1a). Thermodynamic calculation results present a certain amount of η phase and σ phase precipitation when Ti content is greater than 2%. In fact, when Ti content is beyond 1.2%, η phase has already precipitated in a considerable scale (Fig. 3c). In comparison with Al, Ti has a mild effect on γ' solvus and its fraction (Figs. 1a and 2a). Titanium has no

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0921-5093/$ – see front matter
doi:10.1016/j.msea.2007.11.115

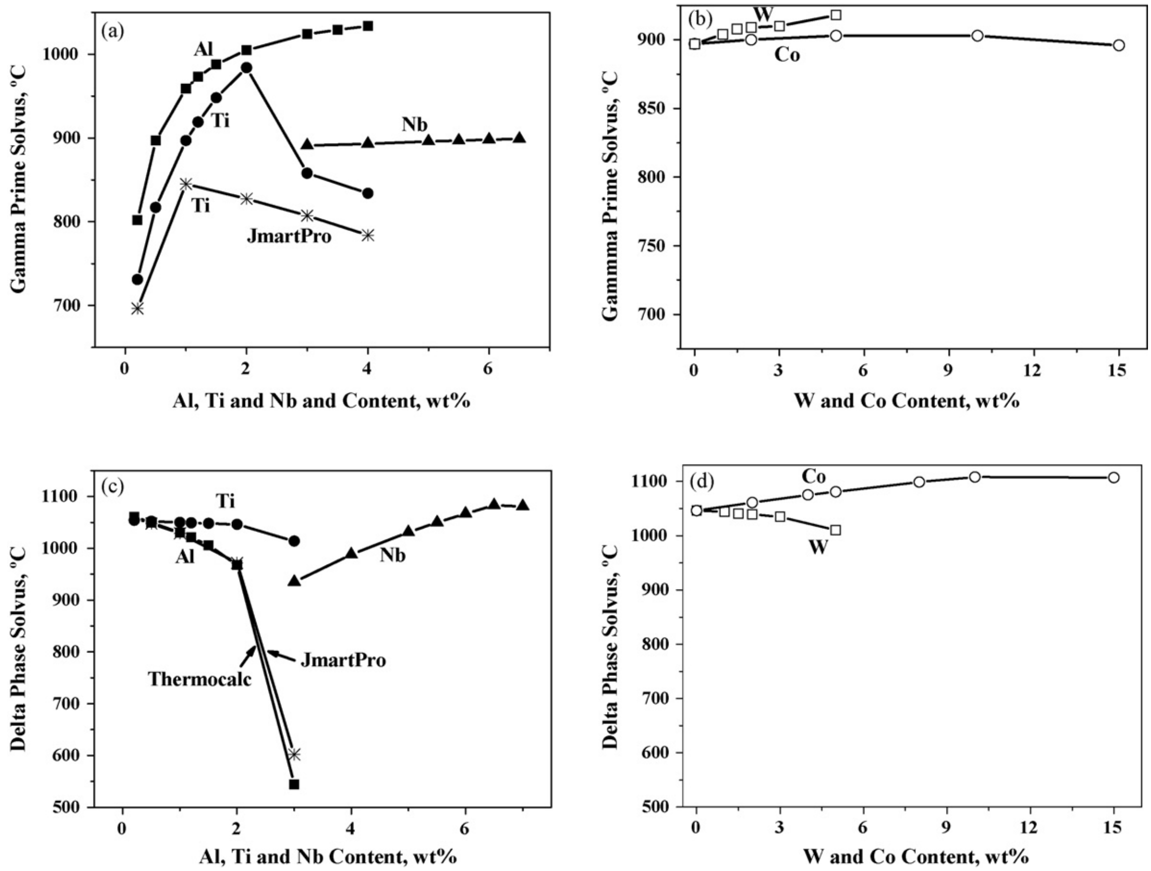

Fig. 1. The variation of Al, Ti, Nb, W and Co content on γ' and δ phase solvus.

significant effect on δ phase solvus (Fig. 1c), but it does decrease the fraction of δ phase though its effect is no greater than Al (Fig. 2b).

In comparison with Al and Ti, Nb has no significant effect on γ' solvus and its fraction (Figs. 1a and 2a). However, it evidently increases δ phase solvus and its fraction (Figs. 1c and 2b).

Mechanical properties are determined not only by precipitation hardening phases but also by the alloy matrix. The matrix can be strengthened by solid solution strengthening elements such as W and Co. Co can reduce stacking fault energy of the γ matrix. Tungsten mainly partitions into γ matrix to strengthen it by solid solution strengthening and reduce bulk diffusivity. Tungsten can slightly increase γ' solvus and decrease δ phase solvus (Fig. 1b and d). Cobalt has a little effect on γ' solvus (Fig. 1b) and it slightly increases δ phase solvus (Fig. 1d). The calculation results also indicate that W and Co both have no significant effect on the fraction of γ' and δ phase because they mainly strengthen γ matrix.

However, when W content is greater than 2%, a certain amount of Laves phase can precipitate and its precipitation temperature is very close to 650 °C (Fig. 3d). With the increase of Co content (substitution Co for Fe), the fraction of σ phase and η phase increases greatly and when its content is beyond 10%, Laves phase can directly form from liquid as primary MC, while the formation tendency of α-Cr decreases remarkably (Fig. 3e). On the other hand, if equal weight of Ni is substituted with Co or Fe, the fraction of main strengthening

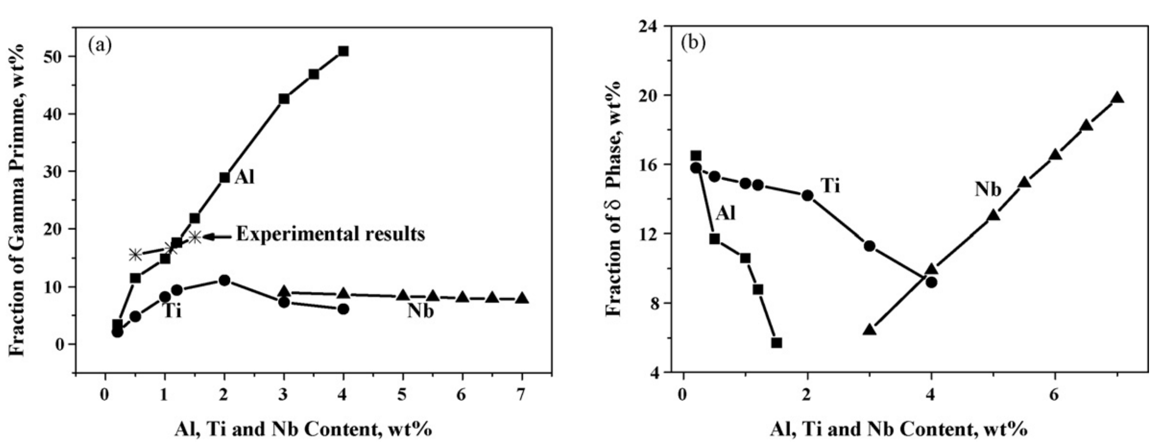

Fig. 2. The variation of Al, Ti and Nb content on fraction of γ' and δ phase.