Key Engineering Materials Vol. 553 (2013) pp 23-28
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/KEM.553.23

Study of the Secondary Phases in Inconel 718 Aged Superalloy Using Thermodynamics Modeling

Felipe Rocha Caliari[1,a], Nara Miranda Guimarães[1,b],
Danieli Aparecida Pereira Reis[1,2,c], Antonio Augusto Couto[3,d],
Carlos de Moura Neto[1e], Katia Cristiane Gandolpho Candioto[4f]

[1]ITA - Praça Marechal Eduardo Gomes, 50 - Vila das Acácias CEP 12.228-900 – São José dos Campos – SP – Brasil

[2]UNIFESP - Rua Talim, 330 – Vila Nair CEP 12231-280 - São José dos Campos – SP – Brasil

[3]IPEN-CNEN/SP and Mackenzie - Av. Prof. Lineu Prestes, 2242, Cidade Universitária CEP 05508-900 - São Paulo - SP – Brasil

[4]EEL-USP - Estrada Municipal do Campinho CEP 12602-810 – Lorena - SP - Brasil

[a]felipercaliari@yahoo.com.br, [b]naraguimma@hotmail.com, [c]danielireis@gmail.com, [d]acouto@ipen.br, [e]mneto@ita.br, [f]katccg@hotmail.com

Keywords: Inconel 718, phase analysis, strengthen mechanism.

Abstract. The evaluation of stability of secondary phases in superalloys is of great importance because of its application under high homologue temperatures. The precipitation hardening Inconel 718 superalloy has high stress rupture and creep resistance, good LCF behavior and high corrosion resistance. Those properties can be obtained due to the high stable matrix based on Ni, Fe and Cr, as well as secondary phases promoters elements such as Ti, Al and Nb. This study aims to analyze the phase stability among a range of temperature from 500°C to approximately 1400°C. The thermodynamic modeling has a high importance to predict the behavior of alloys among equilibrium transition. The microstructure of the system was evaluated using Thermo-Calc software and the selected databases: SSOL4 and TTNI6. This analysis made possible the prediction of the phases presented, compositions and amounts. Results from SEM analysis were used to compare the results obtained, showing good coherence between them.

Introduction

In addition to the study made by Guimarães et. al [1], the application of heat treatment, by solid solution and precipitation hardening, is very important to optimize the mechanical properties of superalloys, for example in the application of jet engines and land based turbines. After heat treatment distribution and crystallographic structure are modified, the study of phase stability becomes very important. The main phases present in Inconel 718 are: gamma prime γ' face ordered $Ni_3(Al,Ti)$; gamma double prime γ" bct ordered Ni_3Nb; eta η hexagonal ordered Ni_3Ti; delta δ orthorhombic Ni_3Nb intermetallic compounds and other topologically closed-packed structures such as μ and Laves phases. δ, μ and Laves phases have low ductility, cause losses in mechanical and corrosion properties [2] .This present work makes part of a broader study of mechanical properties of superalloys under elevated temperatures, especially creep evaluation. The heat treatment applied to Inconel 718, precipitation hardening, has two steps: solid solution and aging treatment. In first step the secondary (hardening) phases are dissolved along the matrix, as well as carbides. In the first is important to note that after 650ºC [3] and with long exposure, γ" transforms in the stable phase δ, which results in loss of mechanical resistance. Thermo-Calc is a useful tool to optimize properties, by promoting precipitation of correct precipitates, saving time and avoiding costly experiments.

All rights reserved. No part of contents of this paper may be reproduced or transmitted in any form or by any means without the written permission of TTP, www.ttp.net. (ID: 200.136.52.143, Instituto de Pesquisas Energéticas e Nucleares (IPEN), São Paulo, Brazil-04/03/13,13:22:26)

Material and experimental methods

The analyzes done via software used two databases available for Thermo-Calc calculations: SSOL4 and TTNI8. The second one is specific for nickel alloys and the first one is applicable to general alloys. The conditions input to null the freedom degree of the system were:

- Pressure: 1.105 Pa
- Temperature: 500-1400°C
- Number of mol for the system: 1
- Components: Cr, Nb, Mo and Ti; with the following composition:

W(Cr) = 0.1839	W(Ti) = 9.5e-5
W(Fe) = 0.1887	W(Co) = 2.3e-3
W(Mo) = 3.01e-2	W(Nb) = 5.05e-2
W(Al) = 4.8e-3	

Figure 1 presents the heat treatment applied on Inconel 718, the high solid solution temperature was chosen to optimize the creep behavior, followed by two aging steps: first at 955ºC and then a second aging step of 720ºC/620ºC, to promote precipitation of additional quantities of γ’ and γ”. Table 1 summarizes the Inconel 718 alloy composition used in this study.

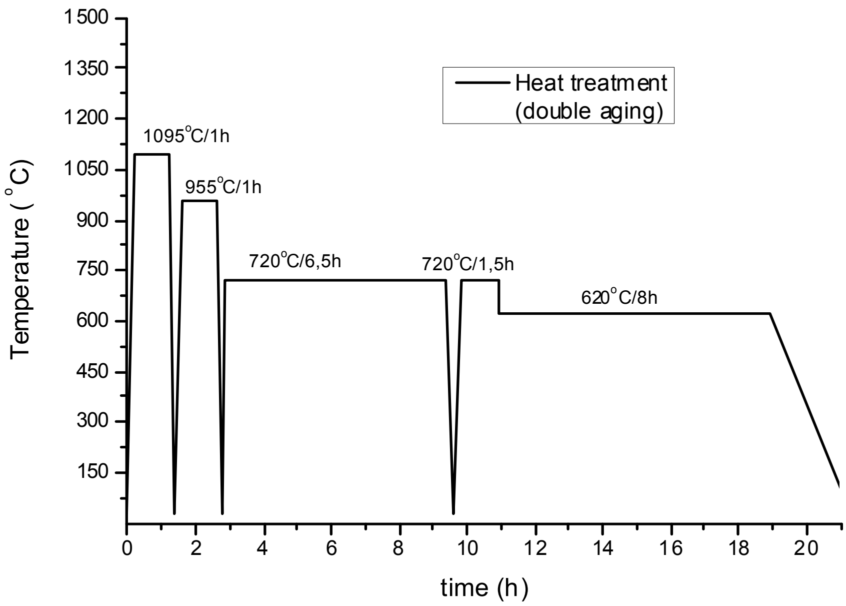


Figure 1: Heat treatment condition applied to Inconel 718.

Table 1: Inconel 718 composition.

Inconel 718 (%wt)			
Cr	Ni	Si	Mo
18.39	52.83	0.03	3.01
Ti	Nb	Fe	Al
0.95	5.05	18.87	0.48

Metallographic preparation: The specimens were prepared by conventional metallographic procedures (transversal sectioning followed by mounting in bakelite). The grinding procedure was conducted using 180, 600 and 1200 grits. Polishing was carried out with cloth covering 6 μ impregnated with 6 μ diamond paste. After that the specimen was polished using a 1 μ cloth covering with 1 μ diamond paste impregnated. Between every procedure the specimens were submitted to ultrasound cleaning, 5 minutes each time. Electrochemical etching was performed by oxalic acid 10% solution, over 20 seconds and using 5 V voltage.

Results and discussion

Thermocalc results: The results of thermocalc simulation applied to Inconel 718 are shown in figures 2 to 5. The figures show the presence of each phase according to the temperature. Figure 2 shows the distribution of all phases together. Figures 3, 4 and 5 relate to Nb, Cr and Al, respectively. Each line number along the graphics corresponds to a phase or state of matter, as follow:

1-fcc matrix, 2-Ni_3Nb, 3-Ni_3Ti, 4-Sigma, 5-Liquid, 6-bcc, 7-Phase ρ

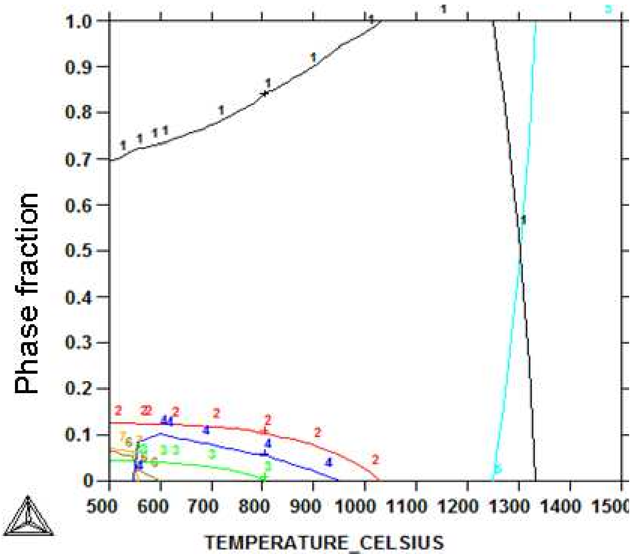


Figure 2: Stability of phases over temperature range.

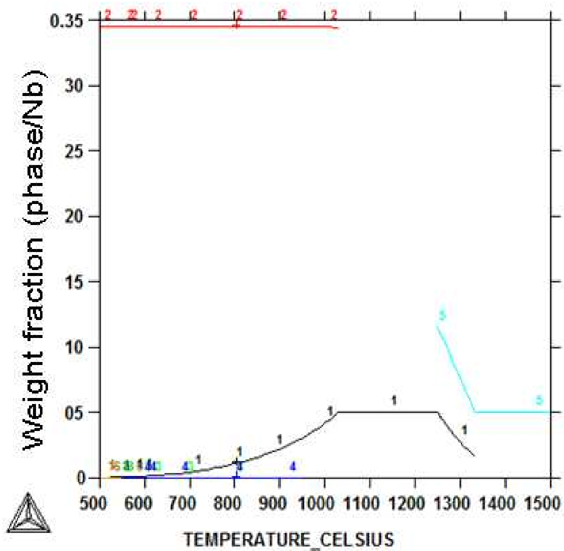


Figure 3: Behavior of niobium and their compounds over temperature.

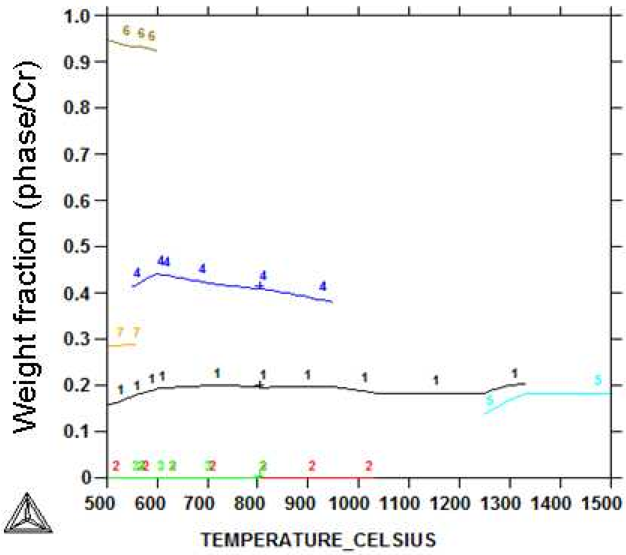


Figure 4: Behavior of chromium and their compounds over temperature.

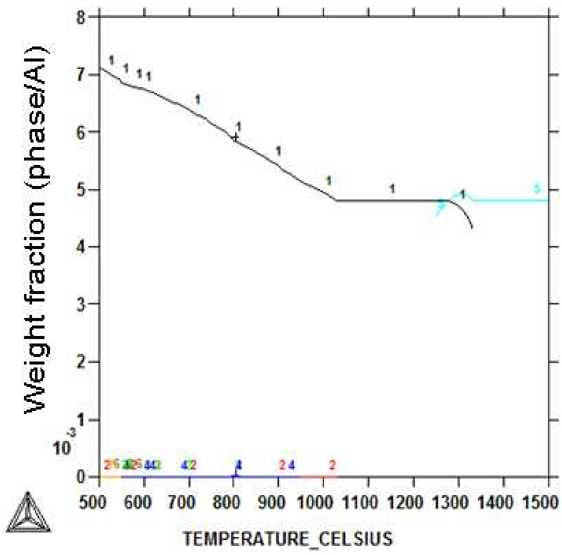


Figure 5: Behavior of aluminum and their compounds over temperature.

SEM image results: Results from SEM were used to evaluate qualitatively the superalloy microstructure, along with the energy-dispersive spectrometry, which helps to identify the chemical composition of secondary phases. EDS of the clear precipitate shown in figure 6 can be found on figure 8, and the EDS of figure 7 is detailed in figure 9. A LEO 1450 VP SEM from EEL/DEMAR, equipped with Oxford Instruments energy-dispersive X-ray spectrometry system was used in this work. The EDS results are shown in figures 6 (EDS figure 8 - as received) and 7 (EDS figure 9 - double aged), as well as the chemical composition of respective precipitates.

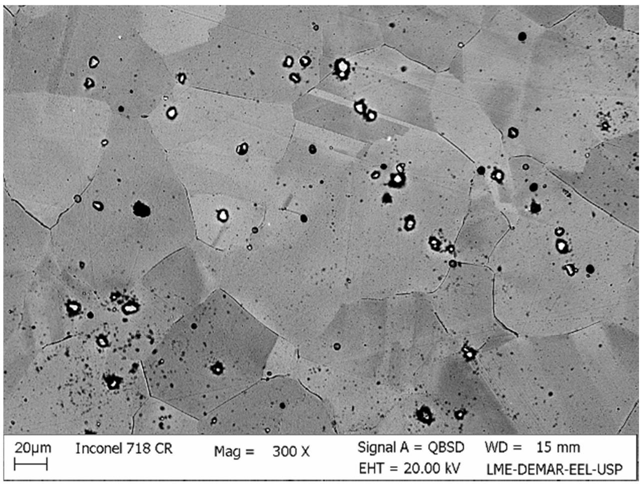


Figure 6: SEM image of Inconel 718 (as received).

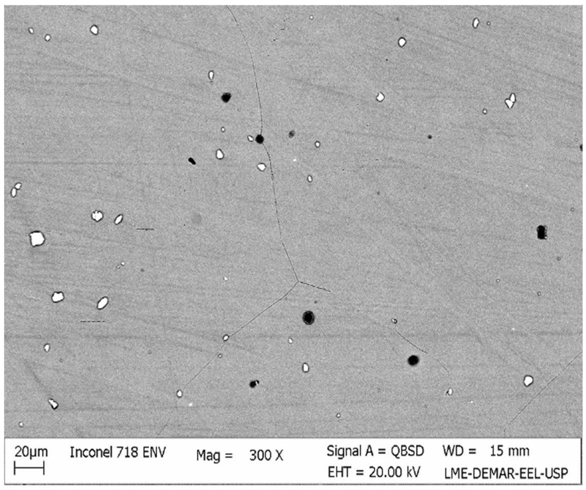
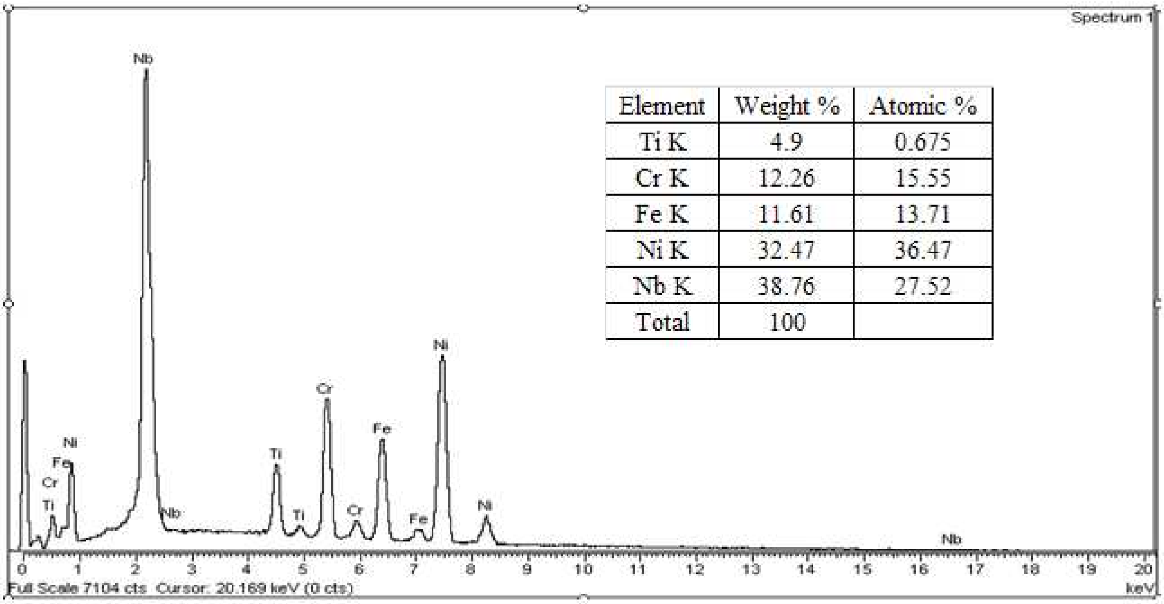
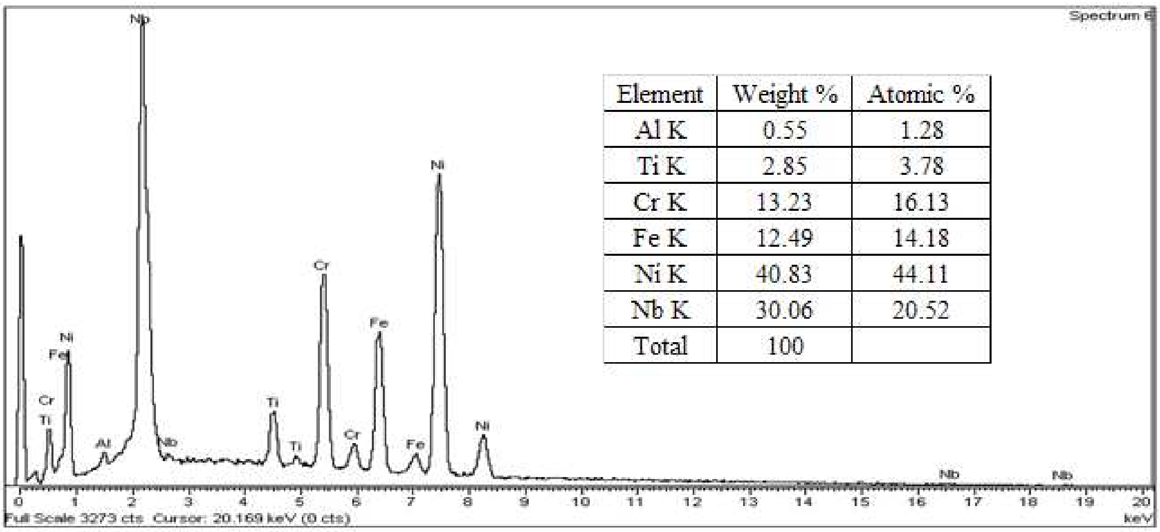


Figure 7: SEM image of Inconel 718 (double aged).



Element	Weight %	Atomic %
Ti K	4.9	0.675
Cr K	12.26	15.55
Fe K	11.61	13.71
Ni K	32.47	36.47
Nb K	38.76	27.52
Total	100	

Figure 8: SEM of Inconel 718 (as received) – This EDS represents the chemical composition of figure 6, and found to be a clear precipitate.



Element	Weight %	Atomic %
Al K	0.55	1.28
Ti K	2.85	3.78
Cr K	13.23	16.13
Fe K	12.49	14.18
Ni K	40.83	44.11
Nb K	30.06	20.52
Total	100	

Figure 9: SEM of Inconel 718 (double aged) – This EDS represents the chemical composition of figure 7. The precipitate is located on the grain boundary.

Discussion: The result from thermocalc analysis shows, in figure 2, the high stability of the gamma matrix between 500 and 1000ºC, and at some point between 1200 and 1250ºC incipient melting takes place. Also from figure 3, the content of Nb dispersed in the matrix seems to play an important role in the stability of the matrix between 1000 and 1250ºC, which is reinforced by the EDS result of a secondary phase on figure 5, the phase is made of Nb and Ni. By the analysis of figure 4, it was detected the presence of Cr in the sigma phase, which confers a brittle behaviour. Al is found in Inconel 718 in the secondary phase gamma prime Ni_3Al, and by the result of figure 5, it seems that gamma prime is well precipitated in the gamma matrix. Between 550 and 900ºC, chromium may be associated to the formation of the sigma phase (σ) in forms of FeCr, FeCrMo. This phase is associated with loss of mechanical resistance at elevated temperatures. One must note that microstructure effects such as morphology of phases precipitated cannot be simulated via software analysis. Thus, for improved conclusions, software simulations must be followed by the study of phase behavior.

Summary/Conclusions

The Thermo-Calc simulation software is an efficient tool to evaluate thermal stability of secondary phases in complex alloy compositions, such as superalloys. This study is consistent with previous publications [4] in relation to the alloy composition and the formation of phases. Formation phase (ρ) may be associated to chromium between 500 and 550ºC, but further investigation is necessary.

Acknowledgments

The authors would like to acknowledge all the financial support gave from CAPES.

References

[1] N.M. Guimarães, T. Sugahara, A.C.O. Hirschmann, D.A.P. Reis and C. Moura Neto, Coelho, G.C. Phase Analysis Using Thermodynamics Modeling for Inconel 718. SAE International (2010)

[2] Fu, S.H.; Dong, J.X.; Zhang, M.C.; Xie, X.S.Alloy design and development of INCONEL718 type alloy. Material Science and Engineering A, (2009), p. 215-220

[3] Durand-Charre, M. The microstructure of Superalloys. CRC Press, (1997), p. 124.

[4] Collier, J.P; Wong, S.H.; Phillips, J.C; Tien, J.K. The effect of varying Al, Ti and Nb content on phase stability of Inconel 718. Metallurgical Transactions A (1988)