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Calphad-simulated second-phase precipitation kinetics during welding of a Ni-30Cr-10Fe alloy modified with Ti and Nb additions

C. M. Garzón(1) and A.J. Ramirez(2)*

(1) Physics Department, National University of Colombia, Bogotá D.C., Colombia, e-mail: cmgarzono@unal.edu.co.
(2) Brazilian Synchrotron Light Laboratory, Campinas, Brazil, e-mail: ramirez@lnls.br
* Corresponding author.

Abstract – A series of kinetic phase diagrams is proposed where the microstructure stability during cooling after welding modified AWS ERNiCrFe-7 nickel alloys is related to Ti- and Nb-content. Primary precipitation of (Ti,Nb)(C,N) carbonitrides and secondary precipitation of Cr23C6 carbides and Ni3(Ti,Nb,Al) gamma-prime intermetallics was predicted as well as identified by analytical electron microscopy characterization.

AWS ERNiCrFe-7 nickel alloy, also known as Inconel filler metal 52 (FM 52), is being widely used for joining Ni-Cr-Fe alloys, particularly Inconel alloy 690. FM 52 exhibits good corrosion resistance, creep-rupture strength, and resistance to stress corrosion cracking (SCC). However, it is susceptible to ductility-dip cracking (DDC) when highly restrained components are welded [1,2]. Significant improvement on DDC resistance of FM52 can be attained if the intermetallic precipitation during welding is optimized [2].

The present work studies the precipitation of intermetallic particles during welding a FM 52 alloy (wt.-%: 10.1 Fe, 29.1 Cr, 0.71 Al, 0.51 Ti) modified with additions of Ti or Nb. Calphad-based numerical simulations and analytical transmission electron microscopy (TEM) characterization were carried out.

TEM-electron diffraction and TEM-XEDS allowed identifying second phase particles in the microstructure as being MX, M23C6 and γ' (gamma-prime).

Calphad-based numerical work consisted in simulating (i) simultaneous growth of both an austenitic dendrite arm and a MX precipitate against a liquid region during weld pool solidification, (ii) concomitant dendritic micro-segregation of alloying elements, and (iii) solid state precipitation of second phases during cooling, inside the austenitic dendrite arms.

Figure 1 shows two computed kinetic phase diagrams where phase domains are related to Ti- and Nb-content for temperatures between 1000 and 2000 K. Alloying additions induce decreasing of both solidification temperature and M23C6 precipitation temperature and strong increase of γ' precipitation temperature. Solidification temperature is strongly influenced by both Ti and Nb additions whereas M23C6 and γ' precipitation temperatures are strongly influenced by Ti additions but influenced in a minor extent by Nb additions.

Figure 2 shows MX growth kinetics with regard to temperature during cooling; computed values as a function of Nb and Ti content of modified alloys are shown. One can see that the higher the alloying content the lower the end temperature of MX precipitation. It was observed (results not shown) that the lower the end temperature of MX precipitation the more irregular the morphological shape of MX precipitates.

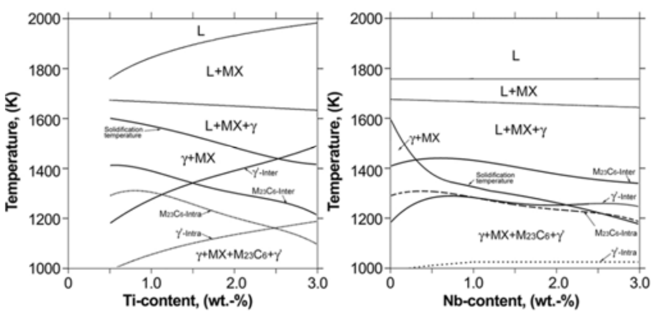

Figure 1: Predicted kinetic phase domains as a function of temperature and addition of Ti and Nb.
L: liquid, γ: austenite, γ': gamma-prime, -Inter: M23C6 or γ' precipitated near the dendrite arm surface, -Intra: M23C6 or γ' precipitated at dendrite arm core.

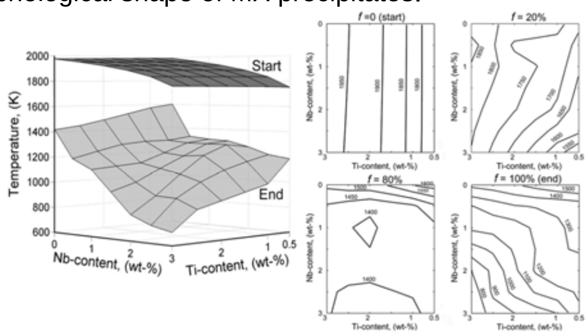

Figure 2: Computed growth kinetics of primary MX. The transformed fractions 0 %, 20 %, 80 % and 100 % are shown as a function of Nb and Ti content of the alloy and temperature. The reverse order of alloying content axis should be noticed.

References

[1] M.G. Collins, A.J. Ramirez and J.C. Lippold. Welding Journal 83 (2004) 39S – 49S.
[2] A.J. Ramirez and J.C. Lippold. Mat. Sci. and Eng.-A 380 (2004) 259 – 271.