Characterization of the Precipitation Sequence of a ASTM A890M Grade E Duplex Stainless Steel Using Computation Thermodynamics and X-ray Diffraction of Extracted Precipitates

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Abstract – Duplex stainless steels are a family of high strength, corrosion resistant alloys developed for marine applications. Typically know for their outstanding ductility and toughness. The properties of these alloys are strongly affected by the presence of undesirable phases such as: carbides, nitrides, carbonitrides, and σ and χ phases. This work elucidates aspects of the precipitation sequence of these phases of ASTM A890M Grade E duplex stainless steel during heat treatments using computational thermodynamics and X-ray diffraction of extracted precipitates. Experimental results from the X-ray diffraction of extracted carbides agreed with thermodynamic modelling.

Stainless steels have been continually improved through optimization of their heat treatments and alloying techniques, and improvements in steel-making practice. Many contemporary allows exhibit impressive mechanical properties and corrosion resistance. A super duplex stainless steel contains nominally (by weight) 25% Cr; 7% Ni; 3.5% Mo; 0.25% N. Ductility and toughness are strongly reduced with σ phase formation, depending on the σ phase volumetric fraction[1]. A large number of undesirable phases can appear in these alloys if an appropriate manufacturing process is not selected[2]: complex chromium and molybdenum carbides, nitrides, carbonitrides, and R, π and χ phases, which all strongly affect the mechanical properties of duplex stainless steels. The intent of the present work is to elucidate the precipitation sequence of these undesirable phases during heat treatments using a combination of computational thermodynamics and X-ray diffraction (XRD) of extracted precipitates.

Specimens of ASTM A890M Grade 6A super duplex stainless steel (Fe-25.69Cr-7.18Ni-3.8Mo-0.74Si-0.014Nb-0.736W-0.016C-0.016Al-0.008S-0.055Co-0.027P-0.049V-0.52Mn-0.72Cu-0.005Ti-0.22N in wt.%) were solubilised in an electric furnace for 2h at 1160°C (cooled in air to ambient temperature) and annealed for 2h at five different temperatures: 640°C, 680°C, 780°C, 820°C and 880°C, after which all samples were then cooled in air to ambient temperature. Thermodynamic modelling was performed using ThermoCalc software. X-Ray diffraction was performed on a Phillips X-Pert PRO diffractometer. Specimens were dissolved with Berzelius reagent (160g $CuCl_2$, 140g KCl, 10g tartaric acid, 925mL distilled water and 75mL HCl) and filtered in a vacuum Millipore filter system with membrane pore size of 0.1µm. Metallographic preparation was conventional.

All specimens studied exhibited the $(Cr,Fe,Mo)_2(C,N)$ carbonitride rich in Cr_2N and $(Cr,Fe)_{23}C_6$ carbide rich in Cr, with exception of the specimen heat treated at 880°C/2h(all in accordance with ThermoCalc predictions). As heat treatment temperatures decreased, the $(Cr,Fe)_{23}C_6$ carbide was enriched in Cr. The $(Cr,Fe)_{23}C_6$ carbide compositions obtained from XRD patterns were compared with the equilibrium compositions calculated with ThermoCalc software and showed good correlation. Comparison between experimental pattern of undissolved austenite and patterns found in the literature suggested that the N content in solid solution was larger for samples treated at higher temperatures, again in accordance with the thermodynamic modelling results. All specimens analysed exhibited σ and χ phases with χ phase predominating. Thermodynamic modelling results have shown a larger amount of σ than χ phase. The difference found between the thermodynamic modelling and the XRD results may be due to the absence of patterns for the σ phase which include additional alloying elements like Mo and Ni.
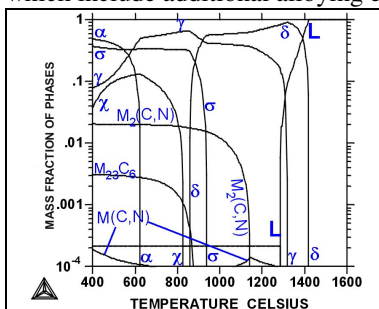
Figure 1: Equilibrium phase diagram calculated with ThermoCalc software
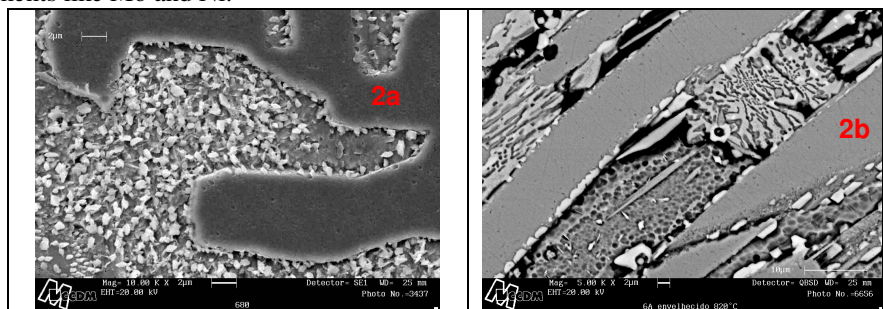
Figure 2: SEM micrographs of ASTM A890M Grade E super duplex stainless steel solubilised at 1160°C/2h and aged for 2h at: (a) 680°C and (b) 820°C. Chemical etch with aqua regia.

[1]. **Martins, M et Forti, L. R. N.** *Materials Characterization.* 2008, Vol. 59, pp. 162-166.

[2] **M, Pohl, Storz, O et Glogowski, T.** *Materials Characterization.* 2007, Vol. 58, pp. 65-71.