MODELLING FOR THE CARBURIZATION OF THE ALLOY – 800 IN LIQUID SODIUM

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INTRODUCTION

The interstitial carbon transfer is one of the most important phenomena concerning the compatibility of metals and alloys with high temperature liquid sodium. In previous communications we reported some methods to evaluate the extent of the carburization (or de-carburization) expected to occur on austenitic steels exposed in a given sodium environment (1, 2). The calculations were essentially based on the criteria developed by Snyder, Natesan and Kassner (3) for the AISI 304 and 316 steels, but some simplifications and minor modifications were introduced to take into account the empirical model performed by Shrock, Shiels and Bagnall (4, 1) and of the coupling of the interstitial carbon diffusion with the selective leaching of the Cr and Ni substitutional alloying elements acting on the same time at the surface of the materials exposed in the hotter zone of the sodium loops (2).

The method developed at ANL make use of structural parameters to take into account the thermal-mechanical history of the material that may influence the carbide precipitation kinetics by altering the grain size and the size and distribution of the carbide particles. That was performed by evaluating the average carbon concentration in the austenitic phase as a function of time during the growth of the carbides following the Nolfi approach (5). The carbide particles were thought as spherical shaped and uniformly distributed throughout the matrix and their growth (the precipitation kinetics) controlled by the carbon diffusion in the matrix (5). Carburization of the AISI type 316 steel exposed at 650 °C in sodium with carbon activity ranging between 0.1 and 0.3 was found to proceed by (Cr, Fe)_{23}C_{6} carbide formation solely at the
grain-boundaries (g.b.), there being no precipitated carbide in the grains (6). This last fact has been generally assumed to occur during the thermal aging of the austenitic steels, and was stated to explain the "sensitization" to the intergranular corrosion of such materials (6, 7).

Although the true carbide morphologies in sensitized steels are known to be very thin dentritic (7), its modelling by a continuous film enveloping the grains was found satisfactory to describe the Time-Temperature-Sensitization (TTS) behaviour of the austenitic steel by the "chromium depletion theory" both for the classical 18%Cr-8%Ni steels (6, 7) and the Ni-rich Alloy-800 (8). Intragranular carbides have been also observed to occur as a later process during the thermal aging above 650 - 700 °C (9, 10, 11). In this work we present a mathematical analysis to produce carbon profile concentrations in austenitic steels as a function of both the environmental conditions and the relevant metallurgical parameters to the characterization of the TTS field for the alloy considered, in the starting "solution annealed" condition. In this case the carbide precipitation kinetics is assumed to be completely controlled by the sole chromium diffusion (6, 7, 8). The Alloy-800 has been retained to be more resistant both to the carburization (12) and to the stress corrosion (13) than the classical 18%Cr-8%Ni steels and it has been chosen for the heat-exchanger tubes of the steam generators for the Superphenix fast reactor plant (13). The present model is then addressed to the carbon transfer analysis for such a material. The behaviour and the modelling for the carburization-decarburization of the AISI type 304 already stated (1, 2, 3, 4) is employed in this work as a reference for a comparative analysis.

CARBON TRANSPORT MODELLING

Let us consider a stainless steel specimen of thickness z exposed to the liquid sodium; if C\text{Na} is the carbon concentration (ppm) in sodium and C\text{Na}_{\text{sat}} is the corresponding saturation level, the Henry's law is generally assumed to hold by neglecting the presence of poliatomic carbon species in the system (the dimeric acetylde has been proved to be present in certain circumstances (14), hence the carbon activity in sodium (a\text{C}_\text{Na}) is expressed by the eq. (1) and (2). (3)

\begin{align*}
a_{\text{C}} &= \frac{C_{\text{Na}}}{C_{\text{Na}}_{\text{sat}}} \quad \text{(1)} \\
C_{\text{Na}}_{\text{sat}} &= 5.03 \times 10^7 \exp(-13.740/T) \quad \text{(2)}
\end{align*}

The carbon activity in an austenitic alloy can be evaluated according to the Natesan and Kassner (3) relationship (equ. 3)