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DIGM Phenomenon as Precursor of DP Reaction in a High Cr-Ni Corrosion-Resistant Alloy

J.C. Spadotto, I.G. Solórzano

Department of Chemical and Materials Engineering, PUC-Rio, Rio de Janeiro, Brazil

The need for corrosion-resistant alloys to sustain aggressive environments at elevated working temperatures resulted in the development of high chromium/nickel-base alloys. The present investigation deals with grain boundary (GB) precipitation phenomena in Alloy 33, with nominal composition 33Cr-32Fe-31Ni-1.6Mo-0.6Cu-0.4N, which presents excellent corrosion resistance and mechanical properties. Particular attention is paid to the phenomenon of diffusion-induced grain boundary migration (DIGM), which combine processes of GB diffusion and motion [1], under aging conditions. This phenomenon has deleterious effect on the intergranular corrosion resistance in Ni-Cr-Fe alloys [2]. Aiming at understanding the mechanisms linking GB precipitation and DIGM in this alloy system, scanning electron microscopy (SEM JEOL-FEG JSM-7100F) and transmission electron microscopy (TEM JEOL 2100F) both coupled to X-ray energy dispersive spectroscopy (XEDS) has been extensively used as main characterization tools.

The SEM image shown in Figure 1 is typical of isothermal aged at 900 °C for 1 hour. This figure shows a GB bowing, pinned by two heterogeneous precipitates, leaving behind a Cr depleted region, as evidence of an event generated by the combined effect of grain boundary migration, diffusion, and precipitation. EDX line scan in Figure 1b shows the distribution of substitutional solute concentration along the yellow line. It is clear the existence of compositional step ahead of the migrating GB. The impoverishment of Cr in the region swept by the GB occurs because of the solute atoms have a much higher diffusivity along the GB, as compared with lattice diffusion, and, consequently, feed faster the growth of the GB pinning Cr-rich precipitates. Although in the early stages of aging the migration of GB precedes the development of discontinuous precipitation (DP) colonies in this temperature (900 °C), it is verified that the intergranular precipitation is dominant in this alloy system.

When the material is aged at lower temperatures (700 °C and 800 °C), the GB diffusion is favored, thereby leading to the development of DP colonies. Also in these temperatures, as at 900 °C, we have observed the occurrence of the GB bulging, as indicated by arrow in the Figure 2a, which indicates that the DIGM phenomenon may be acting as precursor of DP reaction. This observation has been reported to occur in binary alloys [3]. In this figure, besides GB bulging, precipitate phases are observed at stationary GB. With the increase in aging time for 2 h it was observed the development of DP colonies, as shows in Figure 2b. TEM image shown in the Figure 3a presents a DP colony at GB after aging at 800 °C for 5h. Figure 3b is a STEM image obtained in the same region of Figure 3a, showing four precipitates and the DP reaction front. When conducting X-ray elemental mapping in this DP colony different phase composition are revealed. While all precipitates are Cr-rich, Fe and Ni constitute the precipitate at the GB migrating (indicated by arrows). Current investigation focuses on measuring the diffusional fields and on the complete identification of the precipitated phases in terms of composition, crystallography and orientation relationships.

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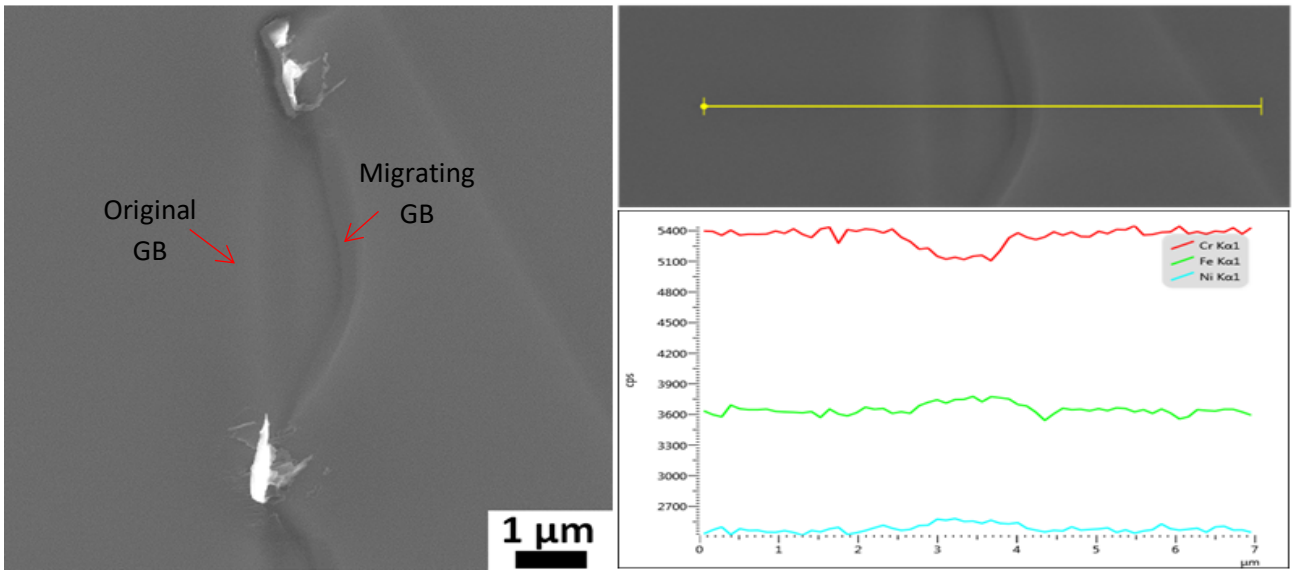

Figure 1. (a) SEM image of Alloy 33 showing a GB bulge pinned by Cr-rich precipitates; (b) EDX line scan showing composition variation of Cr, Fe and Ni elements. Electrolytic polishing.

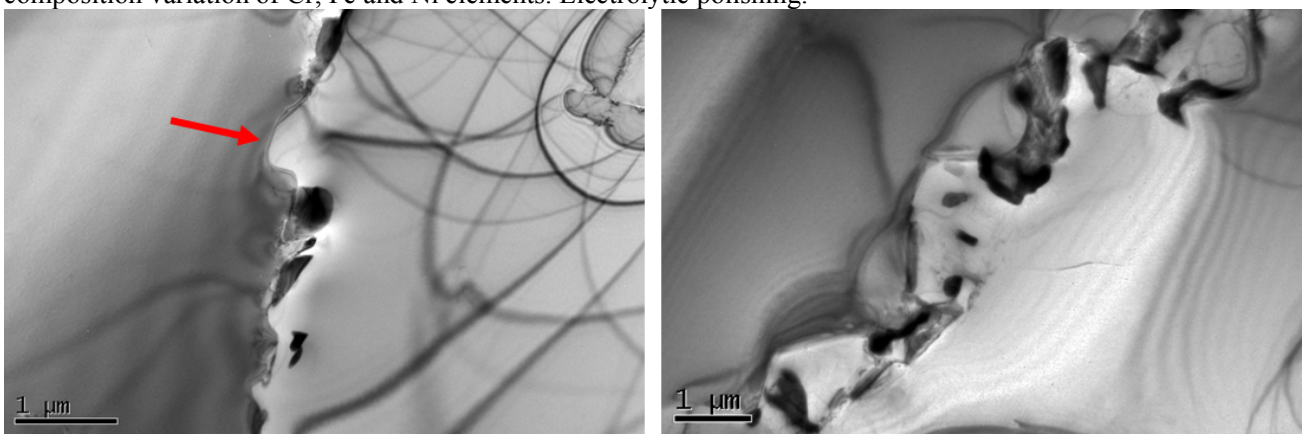

Figure 2. TEM images: (a) GB bulge and GB after isothermally aging at 800 °C for 1 h and (b) DP colony showing precipitates with different morphology after isothermally aging at 800 °C for 2 h. Electrolytic polishing.

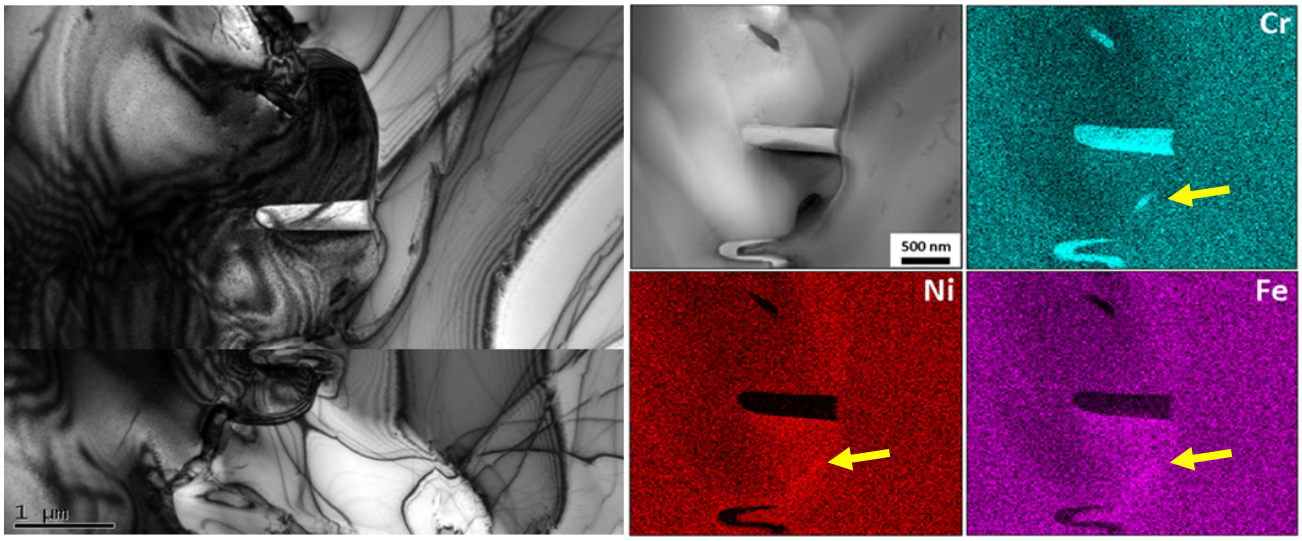

Figure 3. (a) Bright field TEM image showing a DP colony resulting from 800 °C for 5 hours, (b) STEM bright field and X-ray mapping of Cr, Ni and Fe. Electrolytic polishing.

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