Evolution of microstructures in superduplex stainless steels during annealing treatment: characterization and modeling

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Monday, December 16, 2019 at 10:00 am

Amphitheater Jean Besson (Phelma-Campus)

Jury:
Monsieur Alain HAZOTTE, Professeur, Université de Lorraine, LEM3, Rapporteur
Monsieur Mohamed GOUNE, Professeur, Université de Bordeaux, ICMCB, Rapporteur
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Monsieur Emmanuel RIGAL, Ingénieur de Recherche, CEA Grenoble LITEN, Examinateur
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Abstract: Superduplex stainless steels are high-performance stainless steel grades that combine great specific mechanical properties with an excellent resistance to pitting and stress corrosion cracking. The design of new grades with improved properties requires the control of the microstructure and phase transformations occurring during the manufacturing process. Particularly, the rolling steps impart to the alloy the so-called duplex structure, a fine layered microstructure made of two phases, ferrite (δ) and austenite (γ). After the cold-rolling step, an annealing treatment performed at a temperature close to 1100°C give the alloy desired properties. At this temperature, both phases are present in comparable proportions in the alloy, however the layered microstructure evolves towards a more equiaxed and thicker structure within a few tens of seconds. The mechanisms leading to these microstructural evolutions during annealing was studied in this work.

A model Fe-Cr-Ni-Mo-N superduplex stainless steel was produced by a semi-industrial process and supplied in the form of cold-rolled sheets. Its microstructure was studied after isothermal annealing treatments performed within a temperature range of 1060-1180°C up to 300 s. The phase fractions reached the thermodynamic equilibrium during the first tens of seconds of the temperature steady state. A global thickening of the microstructure and a local thinning of the bands were identified. The local thinning was found located at the grain boundaries emerging at austenite/ferrite interfaces similarly to the thermal grain boundary grooving theory, it may also induce fractioning of the phases. Microstructure coarsening was also evidenced by a quantitative analysis.

However, the complex morphology of the phases of the superduplex alloy give rise to morphological heterogeneities during annealing. The low energetic austenitic twin boundaries Σ3 (<111>, 60°) are not affected by thermal grooving. However, differences in grain boundary energy do not explain all the observed heterogeneities, and the morphology of the interfaces in their initial state has proved to be predominant. Through a collaboration, a phase field numerical simulation tool was upgraded to model the evolution of austenitic/ferritic interfaces of various morphologies during annealing. The double interaction of grain boundary grooving and coarsening leads to a rapid evolution of the microstructure.

The interaction of neighboring grain boundaries can locally stabilize an interface, but the microstructure coarsening continues due to the curvature differences that exist between interfaces of a same band and those of adjacent bands.