Cleavage fracture of ferritic stainless steels 18Cr-2Mo: effect of precipitation and grain size

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Thursday, February 11th 2021 – 10:00 a.m.

Amphithéâtre MJK / videoconference

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Abstract: Among stainless steel grades, ferritic stainless steels are used in many applications thanks to their corrosion resistance and attractive properties such as their thermal conductivity and ferromagnetic properties. Their residual nickel content make them economical steels compared to austenitic steels, which are more heavily produced. However, the use of this family of steels is limited by its relatively low toughness at room temperature and below, coming from the lattice friction of the body centered cubic structure that hinders plastic flow. Precipitation and grain size are two microstructural parameters that influence the ductile to brittle transition temperature of ferritic steels. The objective of this thesis is to study and understand the effect of these parameters on the ductile to brittle transition temperature and on the cleavage fracture of ferritic stainless steels containing 18% chromium and 2% molybdenum.

To do so, three castings were produced with the same carbon and nitrogen content. Titanium or niobium were added to two of them. Thermomechanical treatments were chosen to produce six different microstructures for which the grain size, the nature and the location of the precipitation and the carbon and nitrogen content in solid solution vary. These microstructures are characterized by optical and electron microscopies and small-angle neutron scattering. The implementation of a tensile test with notched round specimens allows the determination of the cleavage fracture stress of each microstructure at 20 ° C and -40 ° C and discuss the brittle fracture mechanisms.

The microstructures developed are finally divided into two groups. For Ti, Nb and NbG microstructures, for which the addition of titanium or niobium prevents the precipitation of chromium carbides and nitrides, the cleavage critical stress is dependent on the size and morphology of the intragranular particles. The 4 to 5 µm long cubic Ti (N, C) make the Ti microstructure more brittle than the Nb microstructure characterized by more numerous but smaller Nb (C, N). The grain size is a second order parameter on the cleavage fracture stress of these microstructures as shown by the study of the brittle fracture of the NbG microstructure, for which grain size is ten times larger.

In CrP, Cr and Cr0 microstructures, the presence, or absence, of carbon and nitrogen in solid solution and intra and intergranular precipitations are the consequences of the chosen heat treatments. The presence of precipitates in the grain boundaries, even if they are small (few dozens to few hundred nm), significantly modifies the initiation of cleavage fracture and the value of the ductile to brittle transition temperature. The ductile to brittle transition temperature depends in the first order on the yield stress of microstructures. The cleavage fracture stress is no longer dependent on the size of the intragranular particles as in Ti, Nb and NbG microstructures but on the precipitation of chromium carbides and nitrides at the grain boundaries and on the dependence of the lattice friction stress on the solid solution (Smith's model).

In the light of these results, alternatives to limit the embrittlement of ferritic grades are suggested.