Nitride precipitation and its effects on mechanical properties in high nitrogen austenitic stainless steel

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The beneficial effects of nitrogen on the properties of high-alloyed steels have led to a widespread development of high nitrogen steels (HNS) owing to recent advances in processing technologies. Nitrogen in solid solution is a beneficial element to increase strength level without significant loss of ductility and toughness. Nitrogen is also strong austenite-stabilizing element, and improves the corrosion resistance. Therefore, austenitic HNS constitute a group of promising structural materials that possess a favorable combination of mechanical and corrosion properties. The objectives of this dissertation were (i) to investigate the precipitation behavior, (ii) to examine the deformation behavior of austenitic HNS, (iii) to correlate the precipitation with mechanical properties, and (iv) to clarify the crystallographic features of Cr_2N, which is main precipitate in austenitic HNS.

In chapter 1, physical backgrounds for nitrogen effects were introduced in terms of (i) electronic structure, (ii) interaction of nitrogen atoms with substitutional alloying elements as well as lattice imperfections, and (iii) correlation with properties (deformation and precipitation) of steels.

In chapter 2, time-temperature-precipitation (TTP) characteristics of austenitic HNS were investigated in the temperature range between 700 and 1000℃. The precipitation reaction can be categorized into three stages, i.e. (i) high temperature region (above 950℃): mainly coarse grain-boundary Cr_2N; (ii) nose temperature region: grain-boundary Cr_2N → cellular Cr_2N → intragranular Cr_2N + sigma (σ); (iii) low temperature region (below 750℃): grain-boundary Cr_2N → cellular Cr_2N → intragranular Cr_2N + σ + chi (χ) + M_7C_3. The cellular precipitation of Cr_2N deteriorated tensile properties, especially ductility, whereas the effect of intergranular Cr_2N was almost negligible. The formation of σ phase could be explained by the mechanism that the formation of nitrogen-depleted zone near Cr_2N induced nucleation of σ phase, which was supported by electron microscopy and thermodynamic calculation.

In chapter 3, the deformation behavior of austenitic HNS was investigated with a particular emphasis on deformation twinning. The deformed microstructure was characterized by planar dislocation structure in low strain region, and by stacking faults (SFs) together with well-developed deformation twinning in high strain regime, respectively. The deformation twinning had {111}<112>

crystallographic component, and showed strong orientation dependence with respect to tensile axis: (i) primary and conjugate twinning system cooperated in <111> grain; (ii) only one twinning system was activated in <110> grain; (iii) no deformation twinning observed in <100> grain. At an early stage of deformation, fault pairs composed of two SFs plane and one bounding partial dislocation heterogeneously nucleated, and grew into overlapping SFs, resulting in formation of deformation twinning. The twinning partial was confirmed to be Shockley dislocations with Burgers vector $1/6\ [1\bar{2}1]$, based on the invisibility criteria using two-beam dynamical theory of Howie-Whelan. The formation mechanism of deformation twinning could be accounted for by the three-layer twin model proposed by Mahajan and Chin.

In chapter 4, the crystallographic features of Cr_2N were discussed in terms of crystal structure and order-disorder transition (ODT). Based on the analyses of selected area diffraction (SAD) patterns, the crystal structure of the ordered Cr_2N was confirmed to be trigonal, characterized by three sets of superlattice reflections (001), (1/3 1/3 0) and (1/3 1/3 1). Theoretical model for describing the distribution of nitrogen atoms in Cr_2N superstructure was also derived based on static concentration waves (SCWs) method. During electron irradiation, the superlattice reflection gradually disappeared, indicating that the ODT of Cr_2N occurred. The electron irradiation-induced disordering of Cr_2N can be explained in two-step process: nitrogen atom redistributed (i) along c-axis first, and followed by (ii) perpendicular to c-axis. Based on the neutron diffraction and Rietveld refinement, the occupancies of nitrogen atoms as well as accurate position of metal atom were determined. The partial disordering of nitrogen atoms occurred along c-axis, which can support the above ODT model suggested in the present study.