Thesis title: **Insights into the effects of thermo-mechanical processing on microstructure, mechanical properties, wear, and corrosion behaviour of an ultra-low carbon PH martensitic stainless steel**

Abstract

The growing demand for high-strength structural materials with inherent corrosion resistance for critical applications in space, aerospace, defense, marine, and tooling industries has necessitated alternatives to conventional maraging steels. While maraging steels (e.g., 18%Ni, 300M, AISI 4340) exhibit exceptional ultimate tensile strength (UTS) and fracture toughness, their poor corrosion resistance and reliance on hazardous coatings limit their applicability. Precipitation-hardened martensitic stainless steels (PHMSSs) offer a compelling solution, combining high strength, toughness, and intrinsic corrosion resistance without external coatings.

This study investigates the effects of thermo-mechanical processing and heat treatment on the microstructure, mechanical properties, wear, and corrosion behaviour of an ultra-low carbon Fe-Cr-Ni-Mo-Ti PHMSS. The processing route included homogenization, hot forging, hot rolling, upset forging, solution treatment, sub-zero treatment (ST), and aging. The synergistic effect of additional prior cold rolling (PCR) and aging temperature was investigated systematically on the hot-forged material. Microstructural characterization revealed that introducing PCR before aging causes significant refinement of martensitic blocks, formations of ultra-fine globular reverted austenite with enhanced thermal stability, and finer Ni_3Ti precipitates. These microstructural features were strongly influenced by the extent of %PCR and aging temperature. Volume fraction of austenite was found to depend not only on the phase transformations occurring during isothermal holding but also during cooling. The thermal stability of austenite was found to be reduced for the specimens aged at higher temperatures without PCR, which is attributed to a decreased Ni concentration in the austenite phase, resulting in an elevated martensitic start (M_S) temperature, thereby promoting the transformation of austenite into martensite during cooling.

Mechanical property evaluation demonstrated that early-stage precipitation of Ni_3Ti (at low temperature aging and lower aging time at 510°C) increased UTS and hardness, whereas their coarsening at higher aging temperatures and increased reverted austenite content enhanced ductility and impact toughness. During tensile and impact testing, the deformation-induced martensitic transformation (DIMT) contributed to higher ductility and energy absorption, respectively. The ST specimen exhibited the highest impact toughness due to ultra-low carbon martensite and the absence of Ni_3Ti precipitates.

The wear behaviour, evaluated under both dry and wet (3.5 wt.% NaCl) sliding conditions, revealed enhanced wear resistance in aged specimens. Higher aging temperatures further improved wear resistance due to the increased amount of reverted austenite. The DIMT during dry sliding enhances the wear resistance by delaying oxide layer breakdown and subsequent material loss. The significant reduction in specific wear rate under wet sliding conditions is attributed to effective lubrication and heat dissipation provided by the NaCl solution. In both dry and wet sliding, the operating wear mechanisms were abrasive and oxidative wear; oxidative wear was more pronounced during dry sliding, whereas abrasive wear dominated under wet conditions.

Corrosion behaviour was investigated using potentiodynamic polarization, electrochemical impedance spectroscopy, and immersion tests in aggressive chloride environments. Notably, specimens subjected to PCR followed by aging at elevated temperatures exhibited a significantly higher pitting potential than those without PCR, ascribed to the synergistic effect of thermally stable globular reverted austenite and refined Ni_3Ti precipitates, which collectively enhanced the stability of the passive film, resulting in higher pitting potential and improved corrosion resistance.

Keywords: *Precipitation-hardened martensitic stainless steel; Thermo-mechanical processing; Reverted austenite; Ni_3Ti precipitate; Deformation-induced martensitic transformation; Sliding wear; Pitting corrosion resistance; Passive film stability.*