THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學
國家鋼結構工程技術研究中心香港分中心
Chinese National Engineering Research Centre
For Steel Construction (Hong Kong Branch)

Address: Hong Kong Polytechnic University, Phase 8, Hung Hom, Kowloon, Hong Kong.
Telephone: (852) 3400 8451 Email: cnerc.steel@polyu.edu.hk Website: https://www.polyu.edu.hk/cnerc-steel/

Project Title:

Microstructure control and property optimization of high-strength weldable steels strengthened by nanoparticles for construction applications

Principal Investigator: **Dr. Zengbao Jiao (ME)**

Project Team Members: **Dr. Z.Y. Ding; Ms. B.C. Zhou; Mr. L. Fan; Mr. M.C. Niu**

Progress / Achievement:

In this project, we designed a group of new ultrahigh-strength steels strengthened by nanoscale co-precipitates, including Cu-rich, NiAl, Ni_3Ti , Mo-rich, and FeCr precipitates. Thermodynamic calculations were performed to predict the phase constitutions and volume fractions as a function of temperature and composition. The steels are full austenite at high temperatures, and various precipitate phases including Ni_3Ti, NiAl, Cu, Mo-rich, and laves phase form at intermedium temperatures. Cu additions can dramatically accelerate the NiAl precipitation and increase the particle number density, leading to an effective strengthening effect. To understand the atomistic mechanism of how Cu affects the NiAl precipitation, we performed the first-principles calculation for investigating the interaction of Cu with Ni−Al clusters. Fundamentally, the attractive interaction of Ni−Al clusters provides a chemical driving force for NiAl precipitation. The influence of Cu atoms on the formation energy of Ni−Al clusters was calculated. The formation energy of Ni−Al clusters in the Cu-containing supercells are lower than that of the Cu-free supercells, which indicates that Cu enhances the attractive interaction of the Ni−Al clusters and thereby increases the chemical driving force for NiAl precipitation. As a result, the Cu additions accelerate the NiAl precipitation, which leads to a high number density and volume fraction of nanoparticles. In addition, Cu nanoparticles also co-precipitate with Ni_3Ti intermetallic precipitates. The precipitation mechanism and evolution of precipitate microstructure were studied by using atom probe tomography (Fig. 1). In addition, Mn also promotes the NiAl precipitation by partitioning to the NiAl precipitates. It was found that 1-6% Mn is effective to strengthen steels, while a high amount of Mn would cause the degradation of mechanical properties, because Mn is an austinite stabilizer and retained austinite would be formed by adding a large amount of Mn. The carbon content was set as 0.05 wt.% because high carbon contents may lead to a poor weldability.

Boron was added to strengthen the grain boundary cohesion and prevent the intergranular fracture and the content was set to be 0.02 wt.%. Cr was added to increase the corrosion resistant, but higher Cr concentration would decrease the Ms temperature sharply and limit the solubility of other elements. Based on all the aforementioned information, a class of new nanoscale co-precipitation strengthened steels were developed. Prototype alloys were prepared in a vacuum arc-melting furnace by melting high purity ingredients, and then the melted materials were drop-cast into a copper mold, followed by the cold rolling processes. The cold-rolled specimens were solution-treated and water-quenched to room temperature. The aging treatments were performed at intermedium temperatures for various periods of time. The room temperature tensile tests were performed to investigate the mechanical properties of the steels. A stress-stress curve of a representative steel is shown in Fig. 2. The newly developed steel exhibits a strength of more than 1800 MPa and an elongation of 8%, illustrating a good combination of high strength and ductility.

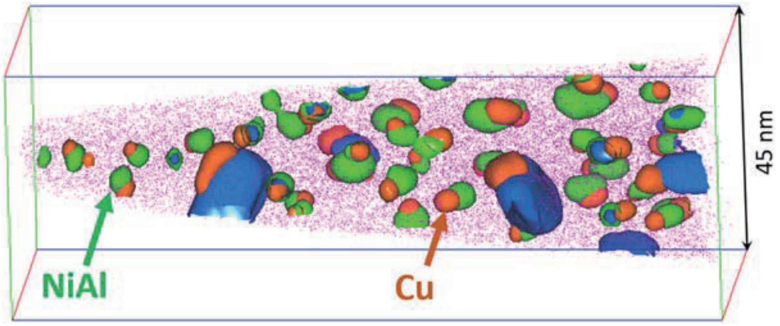

Fig. 1. Co-precipitation of various types of nanoparticles in ultra-high strength steels.

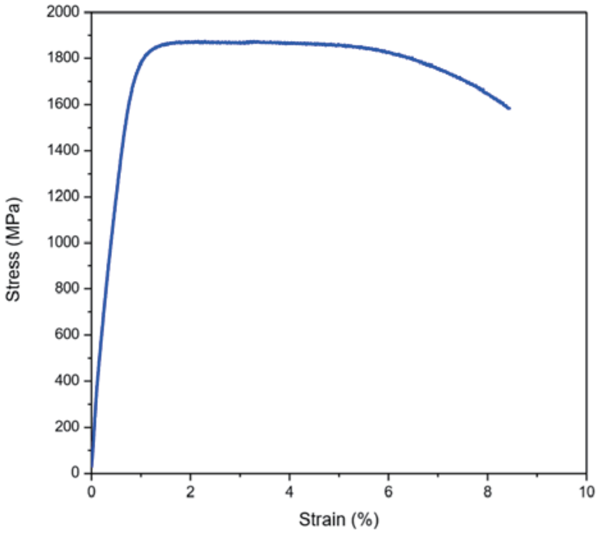

Fig. 2. Tensile stress-strain curve of an ultra-high strength steel.