Grant Recipient Report

Steel Professor Grant

Emmanuel De Moor, Colorado School of Mines

The goal of the project is to develop a procedure for picral-free prior austenite grain boundary etching.

Prior austenite grain size (PAGS) measurements are frequently challenging due to weak etching response to reveal the boundaries. Further, some of the etchants contain chemicals that could be explosive under certain circumstances, notably dry/crystallized picric acid is explosive and Nital etchant preparation needs to be done carefully to avoid strong heat evolution that could lead to boiling and explosion. These environmental health and safety (EHS) hazards have led some laboratories to ban certain etching substances.

The present approach investigates low-temperature melting metals to wet austenite grain boundaries and assess whether liquid metal etching can be used instead of organic chemicals etching. Liquid metal embrittlement is known to occur for steel substrates in contact with, e.g., liquid zinc, where wetting and attack of PAG predominantly over the grain interiors locally weakens the grain boundary strength and cohesion. The wetting mechanism will be explored to evaluate whether it can be employed toward etching and reveal the boundaries for PAGS measurements. The project scope involves the identification of metals and alloys with a low melting temperature that have a good environmental health and safety profile, e.g., are not toxic, non-hazardous to dispose of, result in effective wetting with carbon steels, show preferred wetting of prior austenite grain boundaries over, e.g., lath boundaries, etc. Potential candidates including tin, gallium, lithium, bismuth and their alloys are being assessed.

Various wetting and (back) polishing iterations are being investigated in addition to a variety of steel grades in particular with very low residual contents (notably phosphor, which sometimes is intentionally added to laboratory heats to assist in PAG etching). Light optical metallography is being employed to assess etching response effectiveness from the liquid metal wetting. Energy-dispersive spectroscopy line scanning will be pursued to image and determine the PAG boundary on the etched sample surface. A detailed literature review with PAGS etching procedures has been conducted. Etching approaches including liquid metal etching have been identified. To this end, metals known to cause liquid metal embrittlement with steel alloys were reviewed.

Their potential was assessed as well as an EHS profile via consultation of material safety data sheets. A number of metals were identified and procured and experimental work has been initiated. To date, no successful replacement has been identified. Efforts will continue in the upcoming year. The undergraduate students working on the present project also were involved in sample preparation for projects being conducted by graduate students. This gave the undergraduate students further exposure to ongoing steel research in sheet and coated steels, plate and hot rolled steels, and bar and forging steels.

Dr. De Moor organized the International Symposium on New Developments in Advanced High-Strength Sheet Steels, held 19–22 June 2023 in Vail, Colo., USA. Approximately 130 participants attended the conference. Four Colorado School of Mines graduate students also attended and were supported through the Steel to Students Program, two of which presented on their research and prepared proceedings papers.

Separately, a plant tour of Cleveland-Cliffs Middletown Works and the Research & Innovation Center was hosted for the iron- and steelmaking class, a senior elective and graduate class in metallurgical and materials engineering. Sixteen students participated and travel cost was covered with AIST Foundation funds. ✦