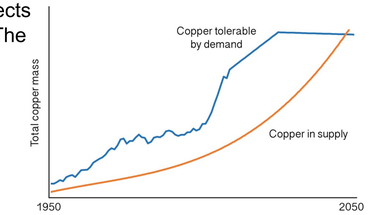
Project 62-L: Maximizing Scrap Recycling by Designing Cu Tolerant Steel Compositions

Spring 2022 Semi-Annual Meeting
Students: Henry Geerlings, Lionel Promel (Mines), Faculty: A. Clarke, K. Clarke, J. Klemm-Toole, S. Seetharaman (Mines), Industrial Mentor: Andrew Kustas (SNL)

CANFSA
Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Background

Steel scrap recycling in electric arc furnace (EAF) steel products is limited by the deleterious effects of residual elements such as copper and tin. The presence of these elements in the steel scrap cycle is projected to increase rapidly with the growing use of electronic components in cars, appliances, and other steel products.



Excess amounts of copper in steel during hot working can lead to surface cracking in a phenomenon known as ***hot shortness***.

Current Cu levels and acceptable limits in scrap and selected steel products, wt. %								
IF Steel	DDQ	Drawing	Commercial	Structural	Wire	Rebar	Scrap	Pig Iron
0.03	0.04	0.06	0.10	0.12	0.07	0.40	≥ 0.23	0.01

Data and knowledge generation related to how scrap blend chemistry affects:

Task 1: Scrap supply chain analysis (year 1-3)
Cost and availability

Task 2: Melting in in EAF (year 1-3)

Task 3: Hot-shortness casting and direct hot charging (year 1-3)

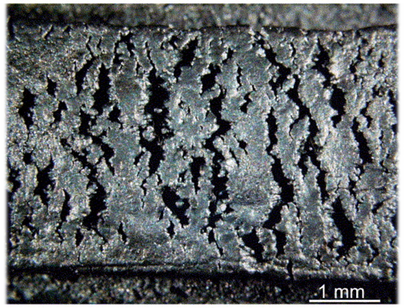
Task 4: Hot-shortness during thermo-mechanical processing (year 1-3)

Task 5: Hot-shortness during Forming, coating and welding (year 1-3)

Task 6: Machine Learning Platform(year 2-3)

Task 7: Techno-economic analysis (year 2-3)

(a)



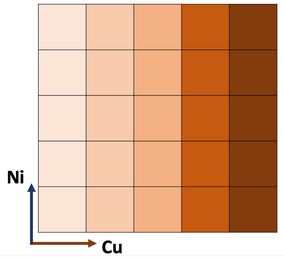
(b)

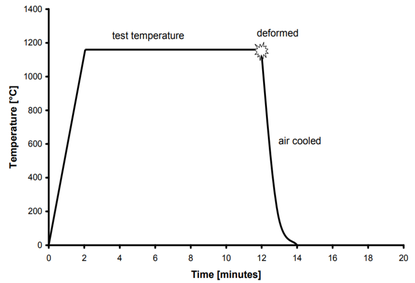
This project intends to model and experimentally assess industrially relevant thermomechanical processing (TMP) conditions for hot shortness susceptibility in various steel product classes, as well as determine the resultant material properties of the product after processing.

Procedures

Experimental Gleeble TMP setup is ongoing. Initial trials have begun with the following parameters:

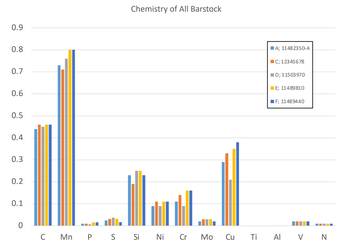
- 1150 °C temperature
- 10-30 min time
- 40 s^{-1} strain rate

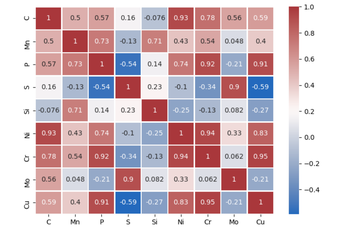




Compositionally graded copper/nickel additive samples are being prepared to explore spectrum of hot shortness behavior as a function of copper, nickel composition.

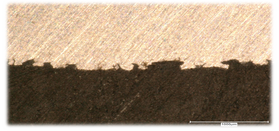
Results





Target Steel Products			
Low Carbon Sheet	Low Carbon Plate	Medium Carbon Bar	High Carbon Wire
		✓	✓

- Two of four steel products have been procured with varying copper contents
- Chemistry, in addition to load/temperature parameters, compose the design space for the machine learning (ML) model
- Quantified hot shortness damage measurements will compose the performance space



Conclusions

The factors reported in the literature which influence hot shortness can broadly be categorized as follows:

Alloy chemistry
- Increasing solubility of tramp elements in Fe (Ni, Si, Mn, S, B)
- Limiting penetration of liquid metal into grain boundaries (P, Si, B, C)

Oxidation conditions
- Temperature, balancing Fe oxidation with diffusion from grain boundaries
- H_2O content

Thermomechanical Processing
- Strain rate, balancing dynamic recrystallization and rate-dependent critical stresses

Microstructure
- Grain size
- Oxide layer morphology

Standardized methodologies for quantifying the presence and severity of hot shortness cracking need to be developed, enabling experiments which investigate the influence of each factor on hot shortness to be designed.

Future Work

- Obtain representative material from industry partners in the low-carbon sheet and low-carbon plate product categories.
- Evaluate hardenability of TMP-ed samples using quench dilatometry.
- Prepare review paper on influencing factors to hot shortness for submission to the Journal of Materials Engineering and Performance
- Establish ML framework to identify correlations between influencing parameters and inform the most productive experiments to perform.
- Integrate with models for scrap composition, energy flow, and processing costs being developed by NREL and industry partners to identify optimized production pathways which minimize costs while maximizing steel recycling efficiency.

Acknowledgments:

This work is supported by DOE-EERE under award number DE-EE0009389. Thank you also to Paul Mason (ThermoCalc), Jason Spice (Vallourec), Mark Richards, Greg Lehnhoff, Bryce Lakamp, Madeline Stelter (Evraz), Luis Garza (Cleveland Cliffs).

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
ADVANCED MANUFACTURING OFFICE
CLIFFS
EVRAZ
Thermo-Calc Software
vallourec
Sandia National Laboratories

COLORADO SCHOOL OF MINES

IOWA STATE UNIVERSITY