Effect of Alloying Elements on the Weldability of Nickel Base Alloys

Allison Fraser, Graduate student, Lehigh University
John DuPont, Professor, Lehigh University

Problem Statement

Background

- High chromium multi-component nickel base alloys provide desired high temperature strength and corrosion resistance for applications in nuclear power industries.
- Weldability of these alloys is strongly affected by variations in composition.
- Current commercial nickel base filler metals can be susceptible to solidification cracking, especially under high-restraint conditions.
- Solidification cracking (Figure 1) can result in reduced strength and corrosion resistance of the welds, compromising the safety of nuclear operators.
- Interstitial elements (carbon, nitrogen) along with carbide and nitride forming elements have been shown to strongly affect weld microstructure and properties in nickel base filler metals.
- The effect and interaction of interstitials and alloying elements on weld solidification and solidification cracking is not well understood.

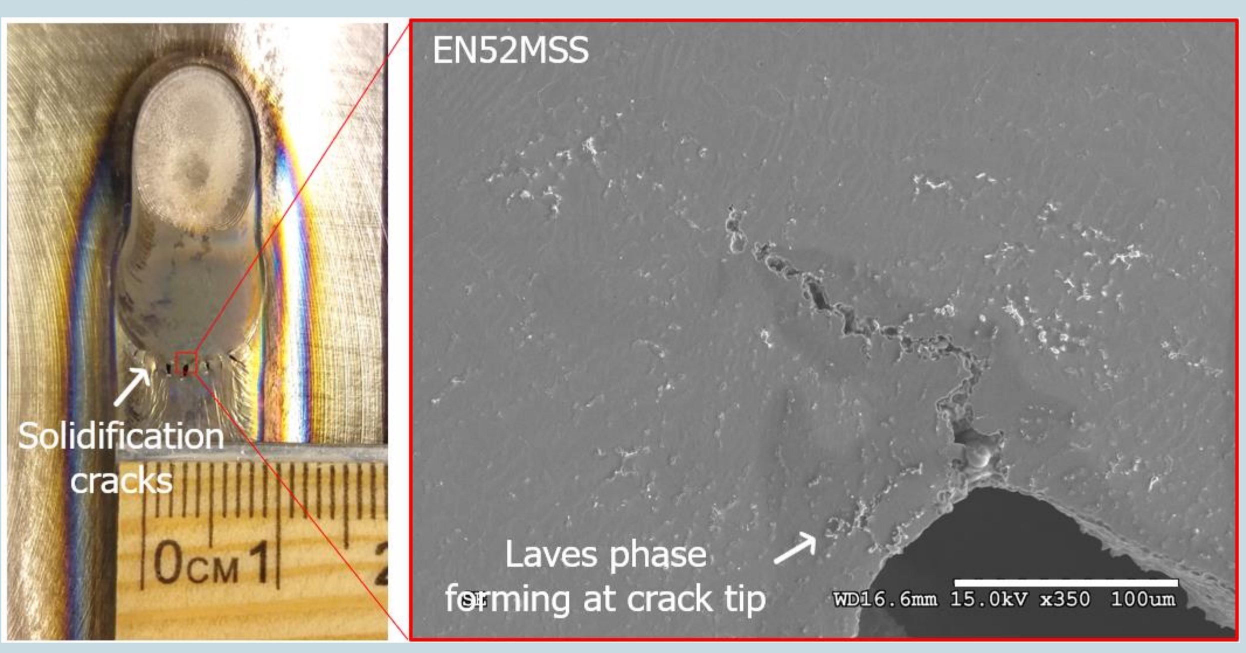


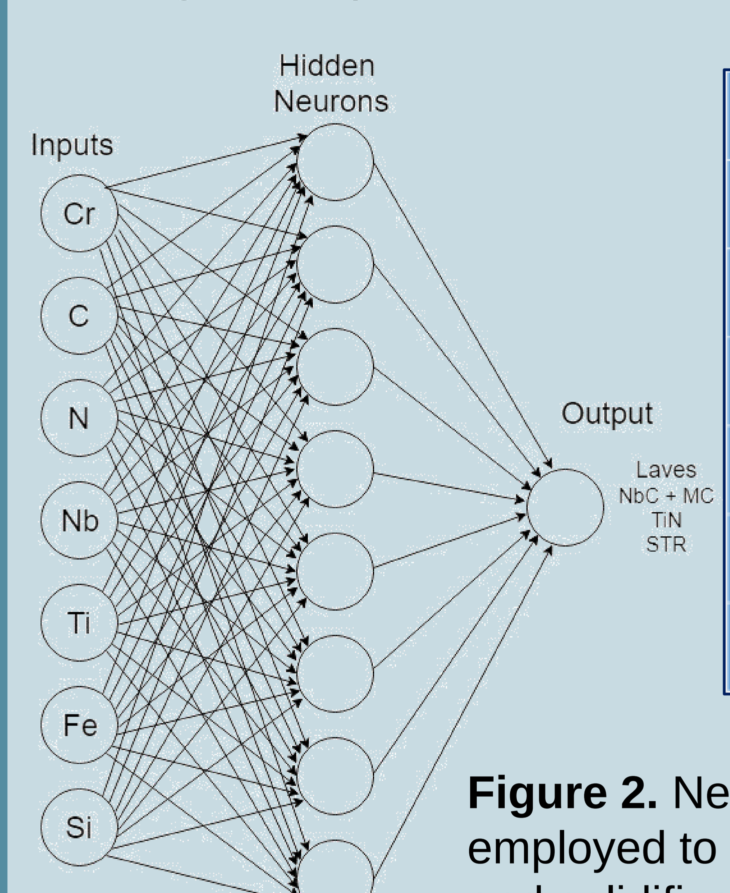
Figure 1. Example of solidification cracks formed during welding, with intermetallic Laves forming at the crack tip.

Motivation

Solidification cracking compromises weld properties. A better understanding of the effect and interaction of interstitial and alloying elements in nickel base alloys may **explain heat-to-heat weldability variations** experienced in industry and will allow filler metals to be **compositionally modified to prevent solidification cracking**, especially under high-restraint conditions.

Objectives & Approach

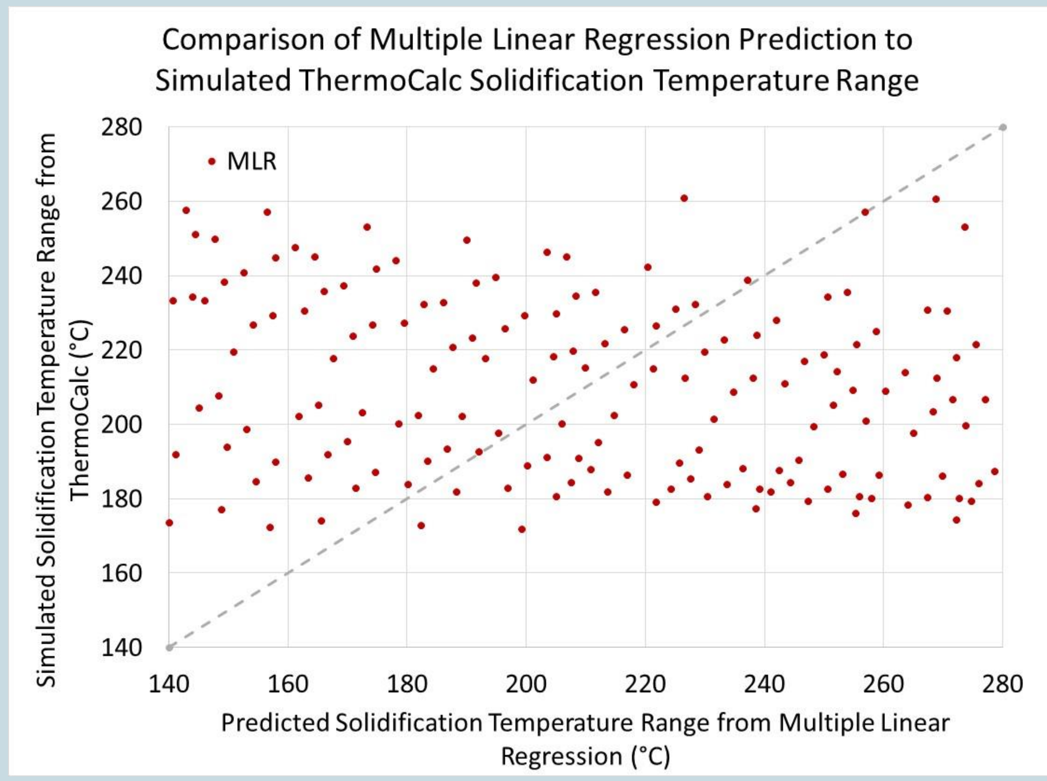
- Determine single and interactive effects of interstitial (C, N) and alloying elements on weld microstructure (phase formation) and weldability (solidification cracking) in filler metal 52i using experimental and computational methods
- Develop full factorially varied composition matrix for alloy development
- Accurately predict resultant phase fractions and solidification temperature ranges by combining ThermoCalc results with a neural network (Figure 2)
- Correct model using experimental data
- Determine suitable alloy compositions that limit Laves formation, reduce solidification temperature range, and promote NbC formation

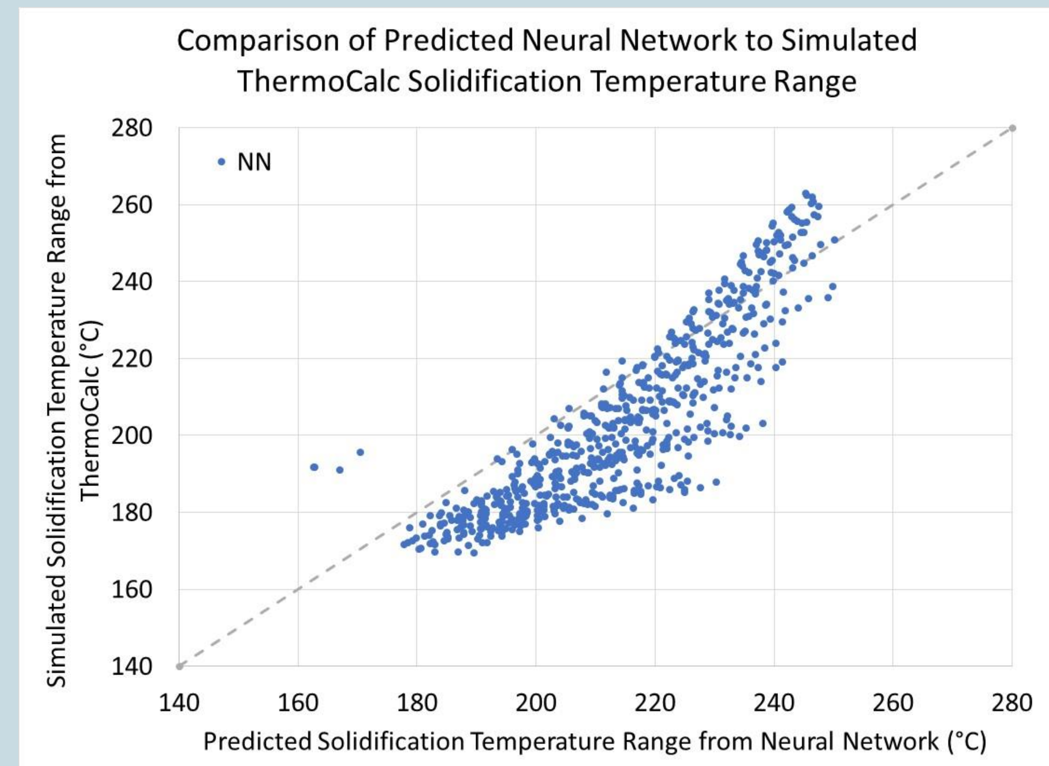


Cr	20	30
C	0.02	0.10
N	0.002	0.060
Nb	0	3.0
Ti	0.2	0.4
Fe	2.5	8.0
Si	0.01	0.10

Figure 2. Neural Network (left) employed to predict phase fractions and solidification temperature range of above composition ranges

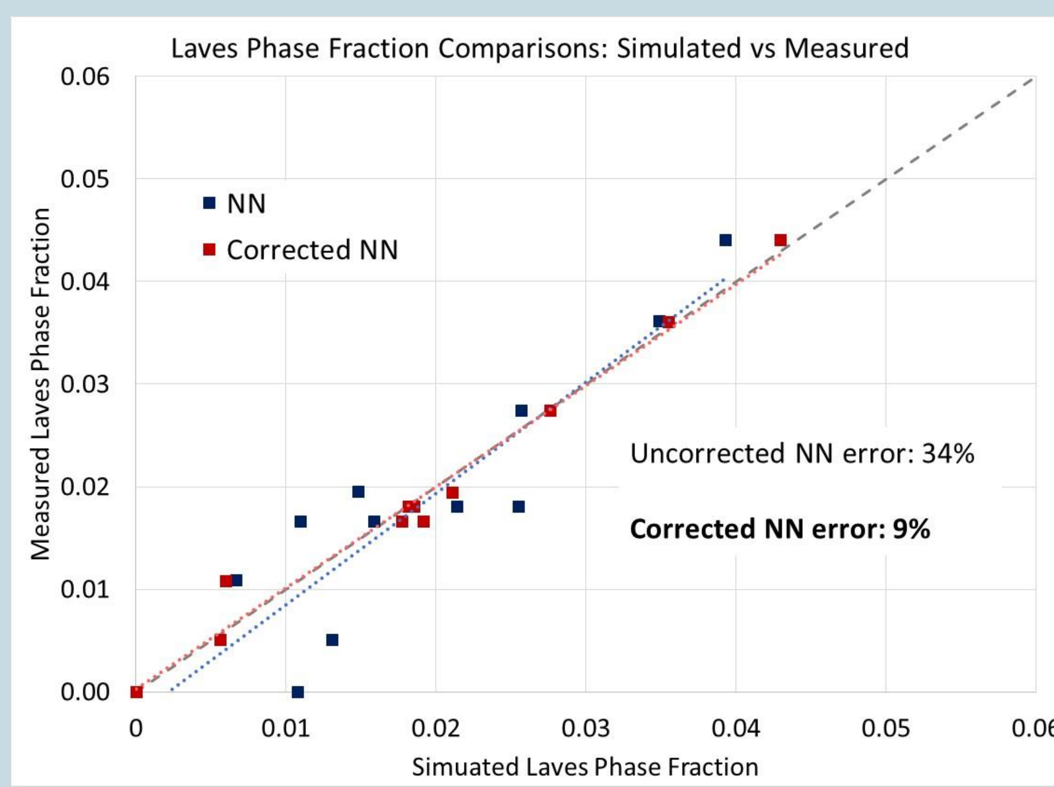
Results & Discussion

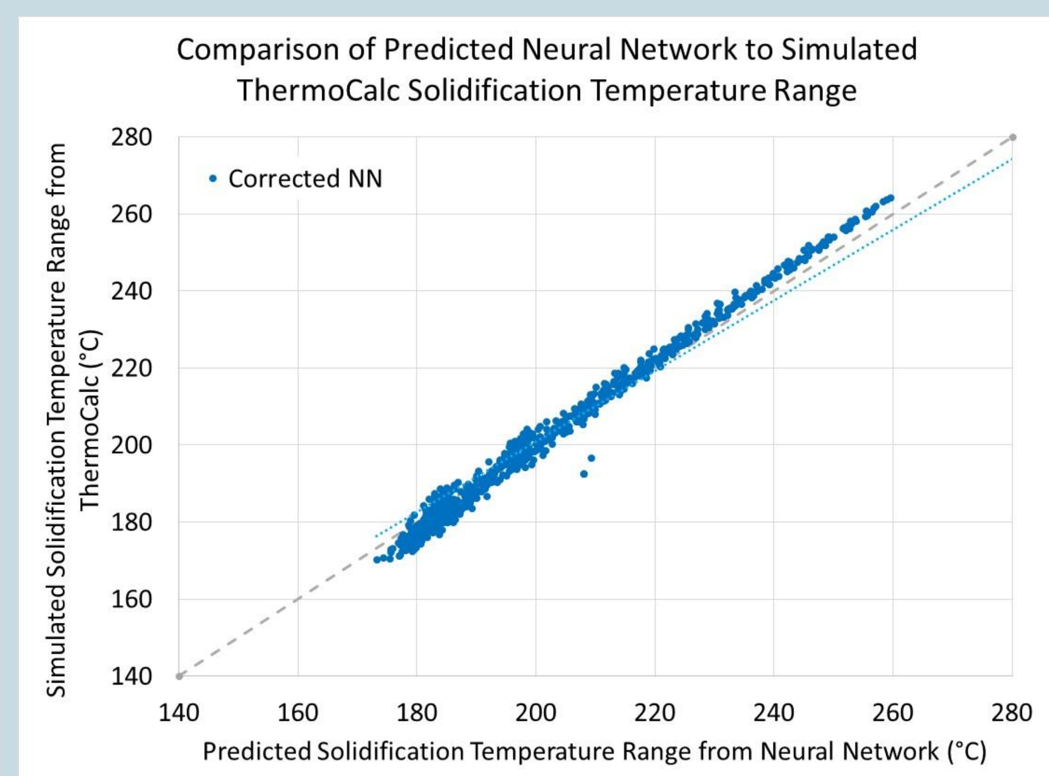




- Multiple linear regression (MLR) model had poor fit to ThermoCalc data
- Resulted in inaccurate predictions for phase fractions and solidification temperature range (STR)

- Neural Network predictive model successfully performed nonlinear regression fitting to improve fit
- Scheil process was automated to accurately train NN with 2187 sets of training data





- NN was corrected using experimental data[1]
- Corrections reduced percent error in predictions from 34% to 9%

- Corrected NN model created excellent fit to ThermoCalc and experimental data
- Accurately predicts phase fractions and STR

Cr	20	21	22	23	24	25	26	27	28	29	30																
C	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10																		
N	0.002	0.005	0.010	0.015	0.020	0.025	0.030	0.035	0.040	0.045	0.050	0.055	0.060														
Nb	0	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
Ti	0.20	0.25	0.30	0.35	0.40																						
Fe	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0															
Si	0.02	0.04	0.06	0.08	0.10																						

- NN predicted phase fractions and STR for full factorial of ranges and steps above – resulted in **10.4 million unique alloy compositions**
- Outputs alloys that best limited Laves (improve weldability), reduced STR, and set maximum NbC + mixed carbonitride (MC) formation to 0.025 weight fraction (balance solidification cracking and ductility dip cracking resistance)

Cr	C	N	Nb	Ti	Fe	Si
23	0.06	0.01	1.0	0.20	2.5	0.02
30	0.06	0.06	1.8	0.25	8.0	0.10

- Optimal composition range determined (left) to improve weldabillity with **no Laves formation**
- Select compositions from optimal range to verify the effect of alloying elements on weldability

Conclusions

- NN can accurately predict 10.4 million unique alloy compositions and determine a range of suitable alloy compositions to minimize solidification cracking susceptibility
  - Minimize/prohibit Laves content, set maximum allowable NbC + MC content, and minimize STR

Future Work

- Select suitable alloy compositions from corrected predictive model for fabrication for weldability testing and microstructural characterization
- Confirm predictive model from experimental weldability and microstructural characterization results

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References

1. DuPont, J. N., et al. "Solidification of Nb-Bearing Superalloys: Part I. Reaction Sequences." *Metallurgical and Materials Transactions A*, vol. 29, no. 11, 1998, pp. 2785–2796.