Si-Cr-Al-Mn Alloy for High Specific Resistivity

Contract Number DE-EE0007866
AK Steel Corp. / Oak Ridge National Laboratories / Regal Beloit Corp.
BP2 (July 2018- June 2019)

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Project Team

AK Steel Corporation, Research & Innovation Center

- Jerry Schoen, Metallurgical Research
- Erik Pavlina, Metallurgical Research
- Garrett Angus, Metallurgical Research
- Tom Thomas, Product Development & Applications Engineering

Oak Ridge National Laboratory, Power Electronics and Electric Machinery Research Center

- Timothy Burress, Electric Machines Team Lead

Regal Beloit America, Inc., Enabling Technology Team

- Jason Kreidler, Director, Enabling Technology
- Paul Knauer, Technology Manager
- Eric Pearson, Materials Science

Overview

Timeline

- Start: May 2017
- End: July 2020
- 39 months

Barriers

- Processability
- Cost – Raw materials
- Grain size and texture control

Budget

	Budget Period 1 (15 months)	Budget Period 2 (12 months)	Budget Period 3 (2 months)	Total Planned Funding
DOE Funds	$404,890	$987,943	$407,166	$1,800,000
Cost Share	$118,291	$282,396	$119,582	$520,269

Partners

- AK Steel Corporation
- Oak Ridge National Laboratory
- Regal Beloit America

Project Objectives

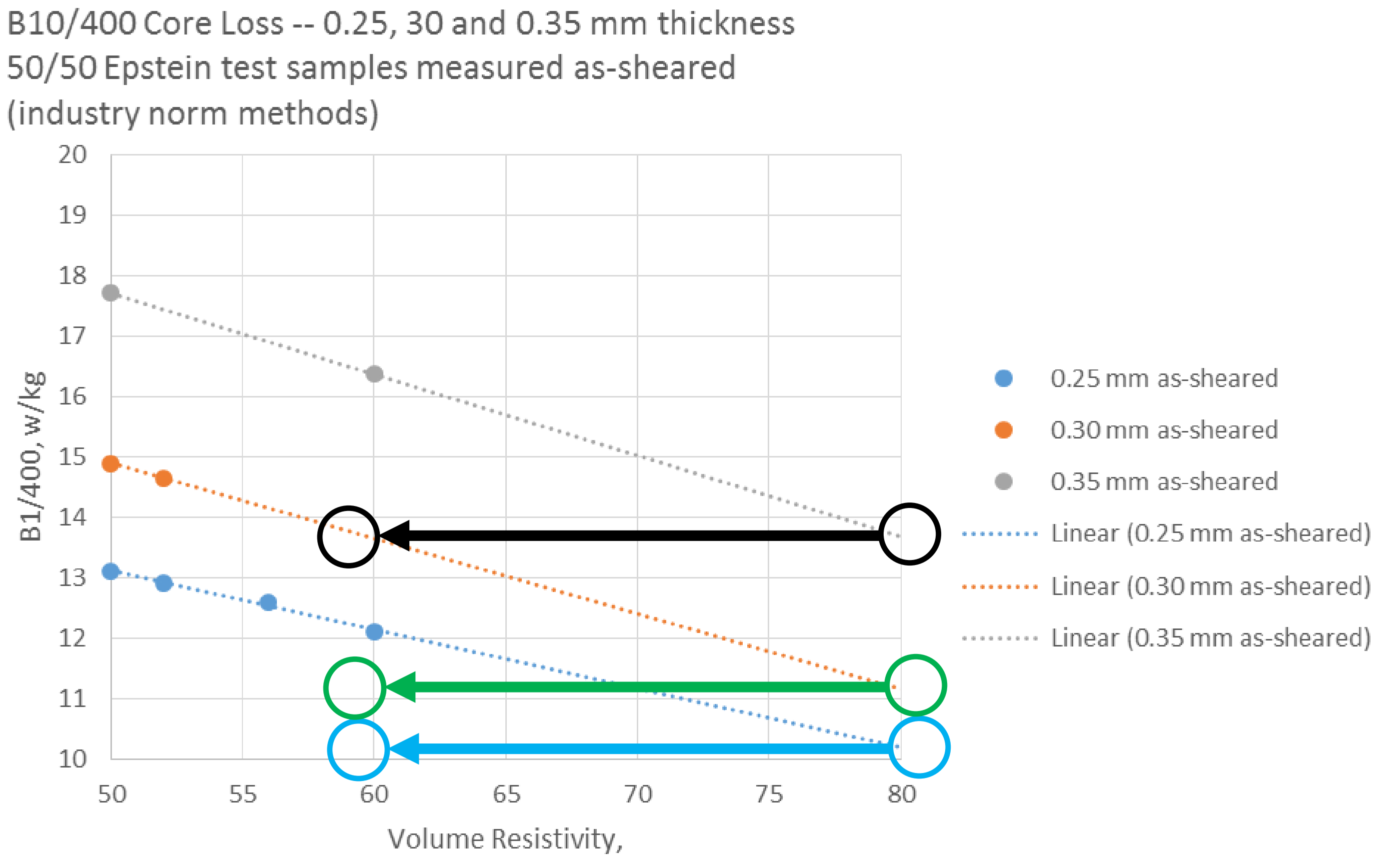
- Objective: >30% improvement in 400 Hz core loss versus existing non-oriented electrical steels (NOES)

- Problem: Achieve a combined chemistry and processing solution to make a NOES product having specific resistivity of 75–80 $\mu\Omega$-cm (comparable to Fe-6.5Si) at a manufacturing cost incrementally above a 3% Si steel

- Approach (BP1): Laboratory melt and test a series of Si-Cr-Al-Mn steels to target resistivity levels
  A. Maintain maximum compatibility with conventional cold-rolled NOES manufacturing method(s)
  B. Determine magnetic/metallurgical characteristics
- Approach (BP2 and BP3): Industrially melt and process a 80 $\mu\Omega$-cm Si-Cr-Al-Mn steel
  A. Determine magnetic/metallurgical characteristics
  B. Design / build / test series of 5HP induction motors using Si-Cr-Al-Mn steel and conventional NOES

High Frequency NOES Today

- Project targets developed from extrapolating from existing high frequency (HF) products
  A. Thickness: 0.25–0.35 mm
  B. Specific resistivity: 56–60 μΩ-cm



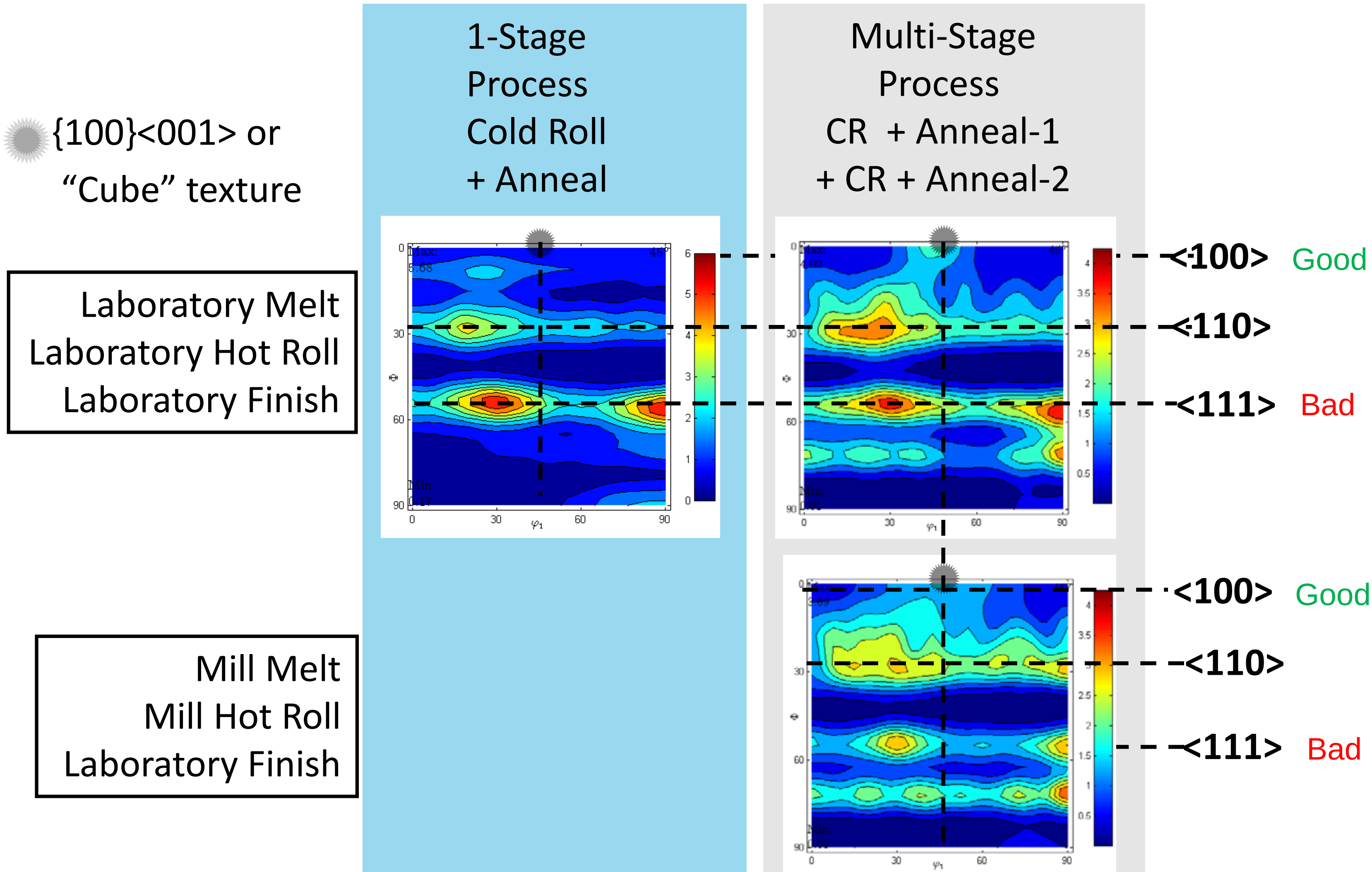
Technical Innovation

Element	Data Range (wt%)	Resistivity Multiplier ($\mu\Omega$-cm/at%)	Alloying Behavior	Effect on Grain Growth	Effect on Strength	Effect on Ductility	\$/$\mu\Omega$-cm	Other Barriers to Use
Si	**0–4**	**5.8**	**α stabilizer**	**Moderate**	**Strong**	**Strong**	**Low**	**Embrittlement >3.5 wt%**
Al	**0–1**	**5.7**	**α stabilizer, N control**	**Moderate**	**Moderate**	**Strong**	**Low**	**Pyrothermic during solidification, AlN precipitation**
Mn	0–2	4.7	γ stabilizer, + S control	Moderate	Moderate	Weak	Low	Grain growth sensitive to S; challenging melt control
Cu	0–1	4.8	γ Stabilizer	Strong	Strong	Moderate	High	Cost; precipitation >1 wt%
Cr	**0–2**	**5.9**	**γ Stabilizer**	**Weak**	**Weak**	**Weak**	**Moderate**	**Cost**
Mo	0–2	7.2	α stabilizer, + S, C control	Strong	Strong	Weak	High	Cost
Ni	0–1	0.9	γ stabilizer	Moderate	Moderate	Weak	High	Cost

All values determined using Fe – 3 wt%Si base alloy

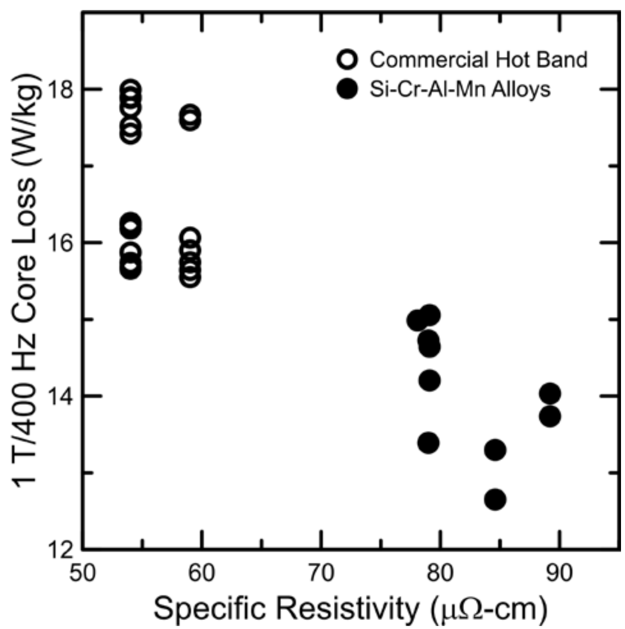
Results – Recrystallization Texture

- Final recrystallization texture comparing lab-made and mill-produced material
- Highly likely that multi-stage processing will be needed obtain high permeability



Results and Accomplishments – BP1

- Achieved design targets for specific resistivity, mechanical properties, and physical processability
- Achieved design target for B1.0/400 core loss
- Magnetic permeability target uncertain
  - A. Poorer texture from laboratory melt + hot rolling technical limitations
  - B. Difficulties simulating full technical capabilities of mill processing in the laboratory
- Currently producing small lots for testing at ORNL
- Alloy design is promising enough to recommend proceeding with BP2 mill-scale trials



Property	Target
Specific Resistivity	≥80 μΩ-cm
Yield Strength	≥400 MPa
Ultimate Tensile Strength	≥500 MPa
Total Elongation	≥10%
Magnetic Flux Density (B50; 5000 A/m)	≥1.55 T
Core Loss (1 T; 400 Hz; 0.35 mm)	≤14 W/kg[1]

Transition Plan

- Working with award partners to evaluate magnetic properties
- Perform manufacture and usage analysis for the transportation sector
    A. Market Assessment
    B. Manufacturing Cost
    C. Capital Investment
- Continued formal plant trials to refine processing windows and properties/performance
- Utilize existing relationships with OEMs to evaluate steels for EV application

Questions?