High-Silicon Steel Sheet by Single Stage Shear-Based Processing

DE-EE0007868

Purdue University/M4 Sciences/PNNL

06/15/17 – 06/14/20

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Overview

Project Title: *High-Silicon Steel Sheet by Single Stage Shear-Based Processing*

Timeline:

Project Start Date: 06/15/2017

Budget Period End Date: 06/30/2019

Project End Date: 12/31/2020

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	CS %
Overall Budget	$1,500,000	$179,147	$1,679,148	10.7%
Approved Budget (BP-1)	$686,240	$93,955	$780,195	12.0%
Costs as of 3/31/19	$653,286	$88,578	$741,863	11.9%

AMO MYPP Connections:

- Next Generation of Electric Machines II- Key Enabling Technologies
- Low Loss Electrical Steel Manufacturing
- Improve electric motor efficiency;
- Increase US manufacturing productivity and efficiency

Project Team and Roles:

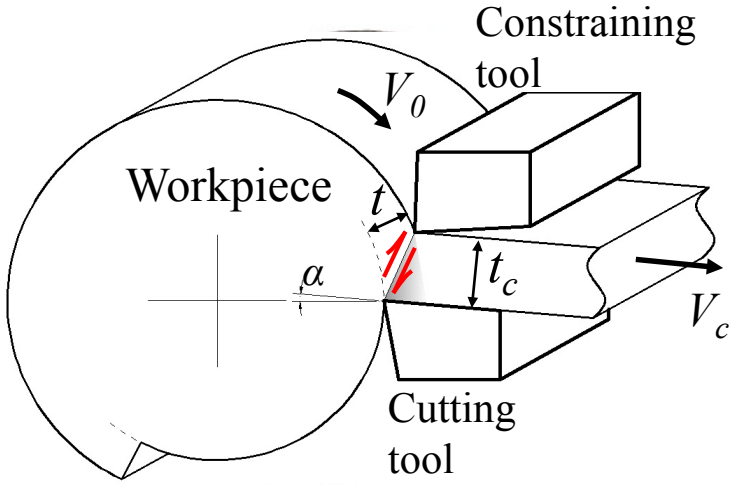
- ***Purdue:*** process development and characterization
- ***M4 Sciences:*** machine/process design
- ***PNNL:*** sheet characterization
- ***Seco Tools:*** tooling development
- ***Strategic Partners***

Barriers and Challenges:

- Low workability of high-Si steels
- Long lead-times (materials/equipment/tooling)
- Paradigm shift in materials processing

Project Objective

- Scale up shear-based cutting process for producing sheet of low-workability alloys in a single step
- Apply new process to high-Si, low-loss electrical steels (6.5 %Si equivalent performance)
- Enable **cost-effective** production of high-Si electrical steel sheet for increased efficiency of motors

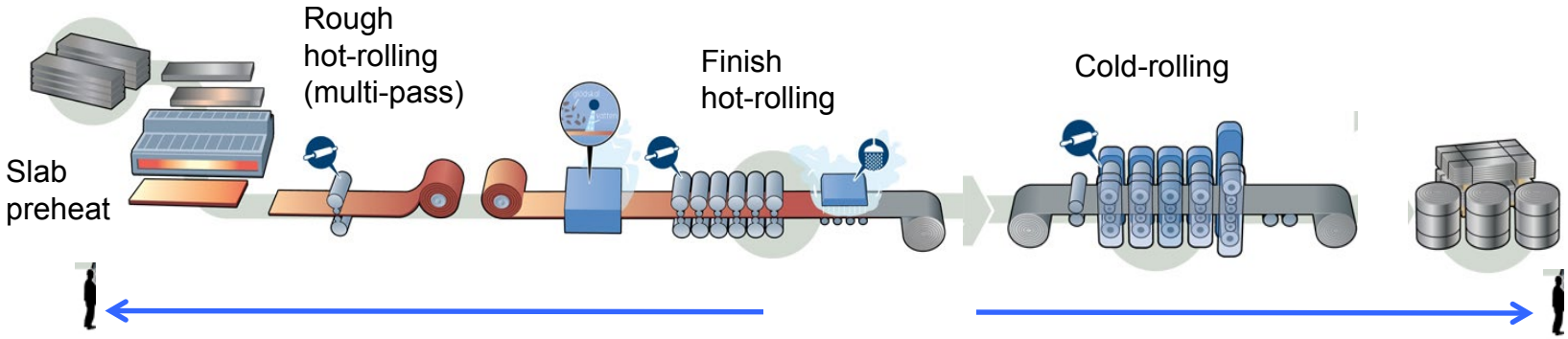


Hybrid Cutting-Extrusion (HCE)

Projected (AMO, 2016) energy saving of ~12,000 GWh/y (0.44%)

Technical Innovation

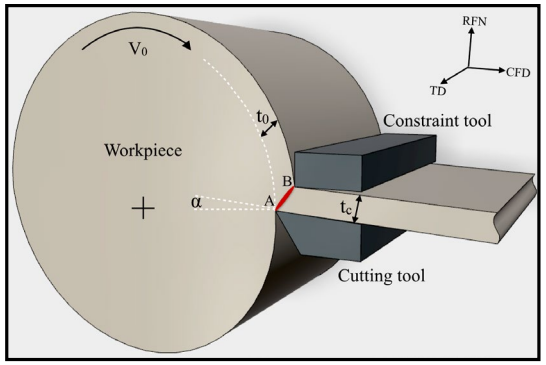
Virtually all metal alloy sheet is produced by rolling processes

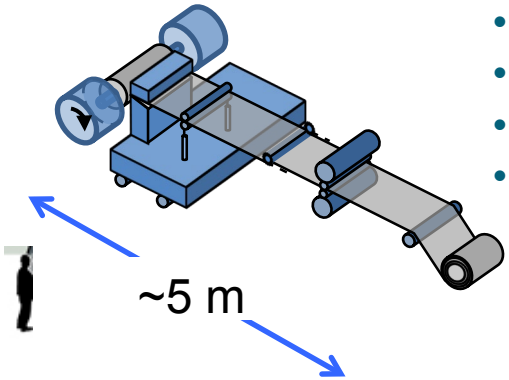


Multi-step reduction, large complex infrastructure, energy intensive

Hybrid cutting-extrusion (HCE)

Innovative application of machining for materials manufacturing

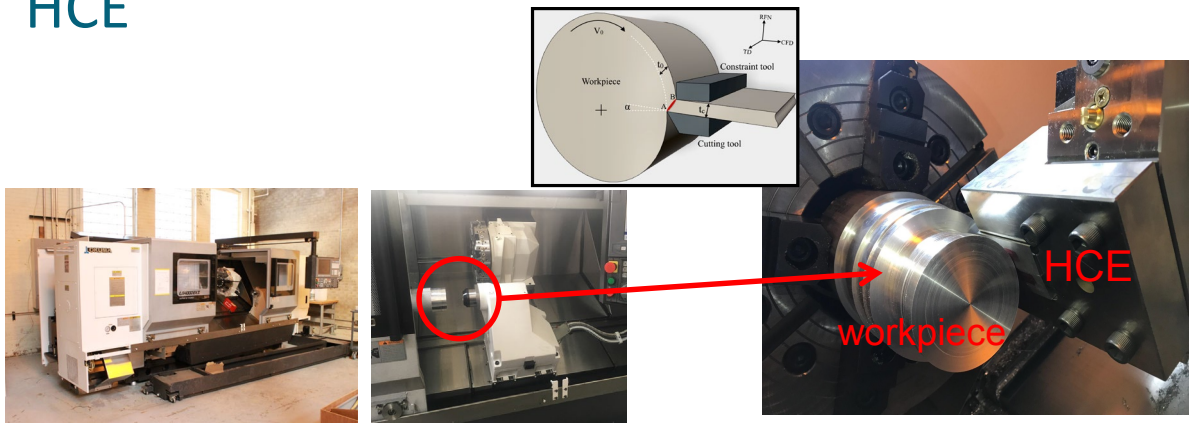




- Single-step process at high rate (>1 m/s)
- Local deformation/adiabatic heating
- Compact infrastructure
- **> 50% process energy savings**

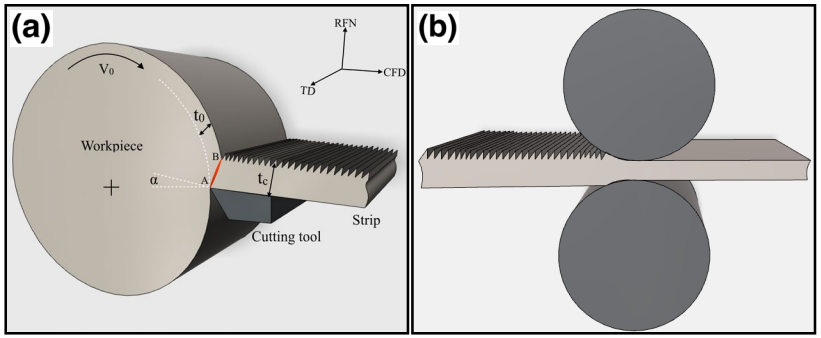
Technical Innovation

HCE



- Scaled production
- Wide range of alloys
- New microstructures
- Transformative technology

Free Machining + Cold Rolling process (FM + CR)



- Alternative process
- Unique benefits

Technical Approach

Phase 1

Small scale HCE
- Fe4Si, Fe6Si
- Al alloys, brass
- Background IP

Alloy development – FeSi-X
- Processing in HCE
- Format for workability

Mfg Development
- Equipment/tooling/process
- HCE and FM+CR
- Range of alloys
- New mfg science & IP

Process scaling

Stage 1 scaling: 50mm x 0.3mm

Phase 2

Process scaling – 2 stages
- Equipment design
- Prototype sheet/strip
- Model alloys
- Fe4Si4Cr

Process Capability
- Target scale
- Quality
- Material properties
- Processing characteristics

Pre-production

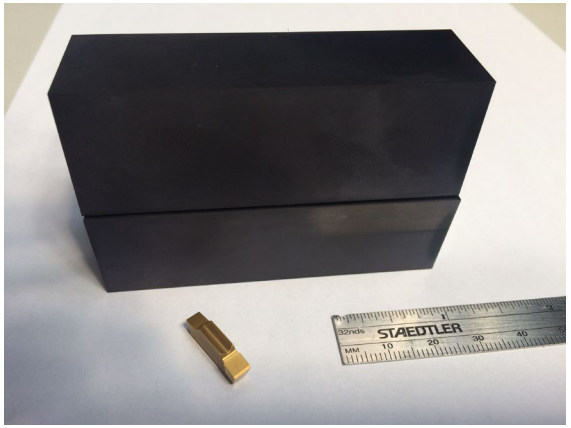
Stage 2A scaling: 100mm x 0.3mm

Stage 2B scaling: 150mm x 0.5mm

Technical Approach

Risks and unknowns:

- Tool design and performance (e.g., large size carbide tools, edge geometry, life)
- Sheet quality attributes and stampability
- Equipment/workpiece design
- Long industry lead times



Large size (first-of-a-kind) carbide HCE tools

Unique execution attributes:

- Prior success in commercializing materials processing technologies (research → product prototyping → commercial adoption)
- M4 Sciences and Purdue.

Results and Accomplishments

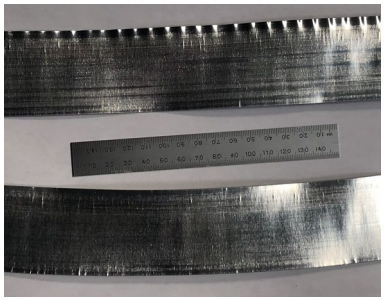
Milestones complete

M1 High-Si alloy development/characterization

- -Fe4Si4Cr alloy selected (D1)
- -Small-scale HCE strip (to 6 mm x 0.4 mm)
- -Stage-1 large cast ingot > forging to workpiece

M2 Stage-1 process: 50-mm strip

- -50-HP machine installed and process prototyped
- -50mm process demonstrated on Al alloy and Brass;
  - Fe4Si4Cr in progress (D2)



Al6061-T6

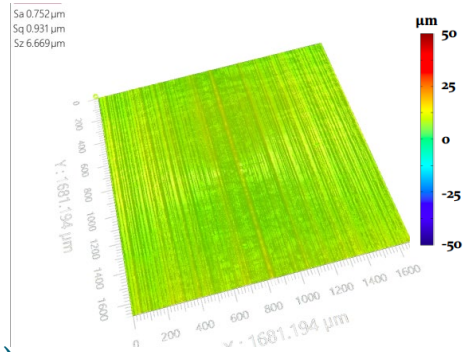
Naval brass

48-mm wide strip

Fe4Si4Cr
5-mm wide strip

Results

- New Fe4Si4Cr alloy for process scale-up
- First 50-mm wide HCE and FM+CR strips
- Surface finish < 1 µm Ra/Sa
- Unique microstructure and texture
- Provisional patent and other IP
- Mechanochemical effect discovery (press coverage)



Surface
roughness
0.3 - 0.7 µm Sa

Transition

2018-19 | 2020-21 | 2021-

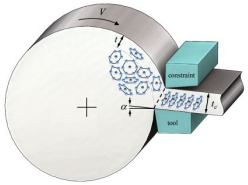
Shear-based technology
HCE and FM+CR
Alloy development
Scaled test-bed

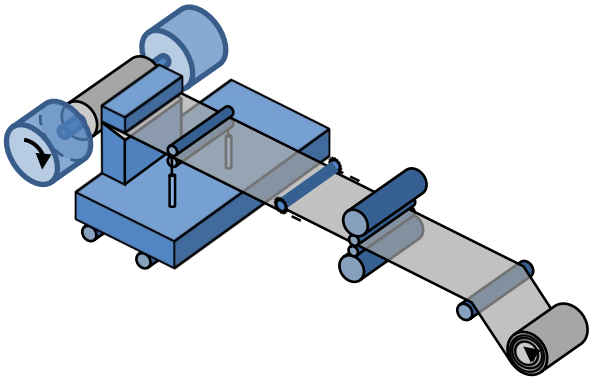
Scaled Processing
Pre-Production
Strategic Partner (SP)
Publications

Development agreement with SP
Pilot production

Fe-Si sheet by HCE or FM+CR
Range of alloys (steel, Al, Ti, Cu)
Commercial funding

Technology development → IP Licensing/JDA → Production





- Strategy
  - Technology development
  - Strategic partners – markets engaged early adopters (Seco/Sandvik, General Cable, Spirit)
  - IP licensing and commercialization via Purdue/OTC
  - Pursue funding for production and commercialization