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

DE-EE0007868

Purdue University/M4 Sciences/PNNL

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Overview

Timeline

- June 2017 – June 2020
- Two 18-month periods
- Project ~30% complete

Budget

x $1000	Period 1 6/17-11/18 Costs	Period 2 12/18-6/20 Costs	Total Project Planned Funding
DOE Funded (spent to date)	686 (354)	814	1,500
Cost Share (spent to date)	94 (36)	85	179

Partners/Roles

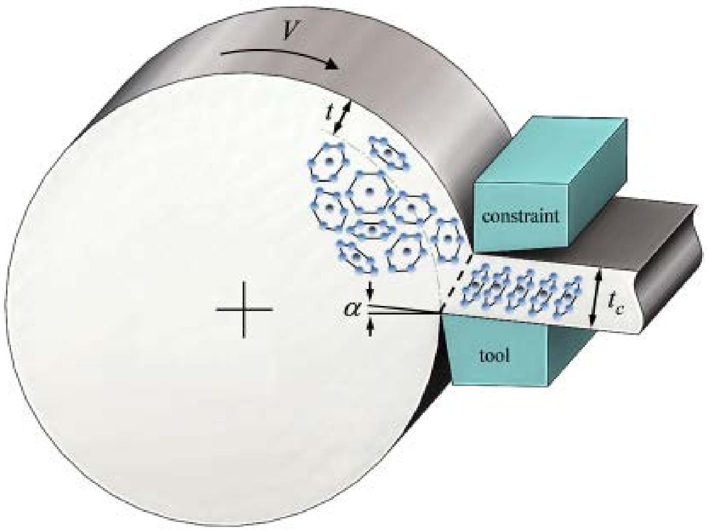
- Purdue University - process development/characterization, patents
- M4 Sciences - machine/process design
- PNNL - sheet characterization
- Seco Tools - tooling development
- Steel OEMs - raw material, strategic partners

Barriers

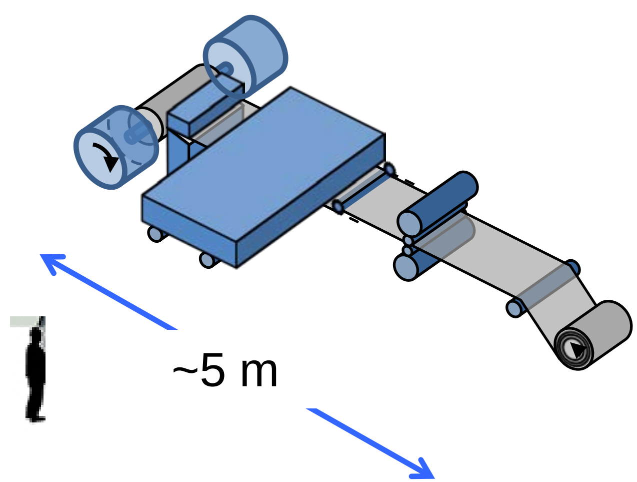
- Workability of high Si content steels
- Sheet quality attributes and stampability
- Availability of raw material in suitable form
- Tooling and special fixtures

Project Objective

- Scale up hybrid shear-based cutting process; enables single-step thin sheet production from alloys of low workability.
- Apply the new process to high-Si, low-loss (80 μΩ-cm) electrical steels
- Enable high-Si electrical steel sheet production for increased-efficiency electric motors.

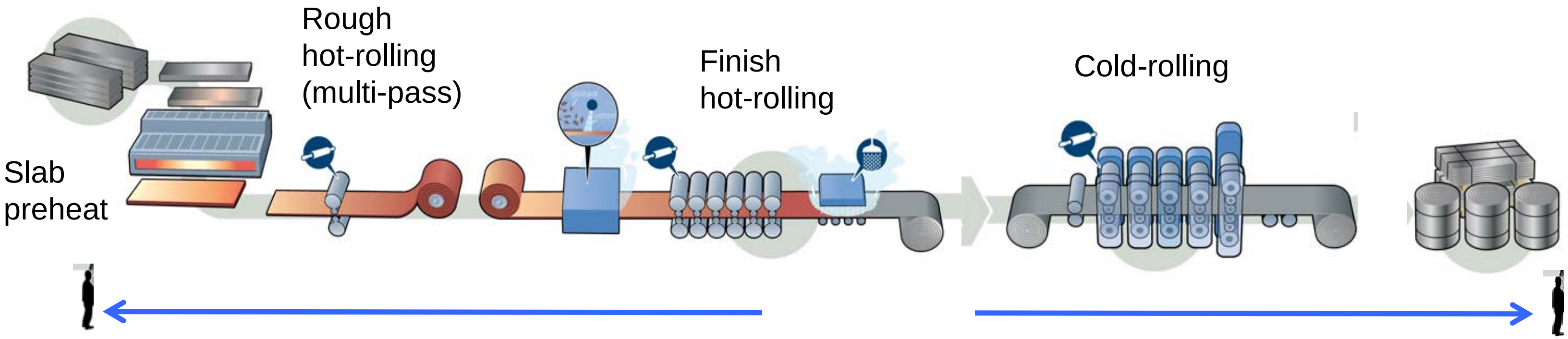


***Hybrid cutting** - proposed process*



Technical Innovation

- Virtually all metal alloy sheet is produced by rolling processes



Multi-step (incremental) reduction, energy intensive,
large infrastructure, limitations for low-workability alloys

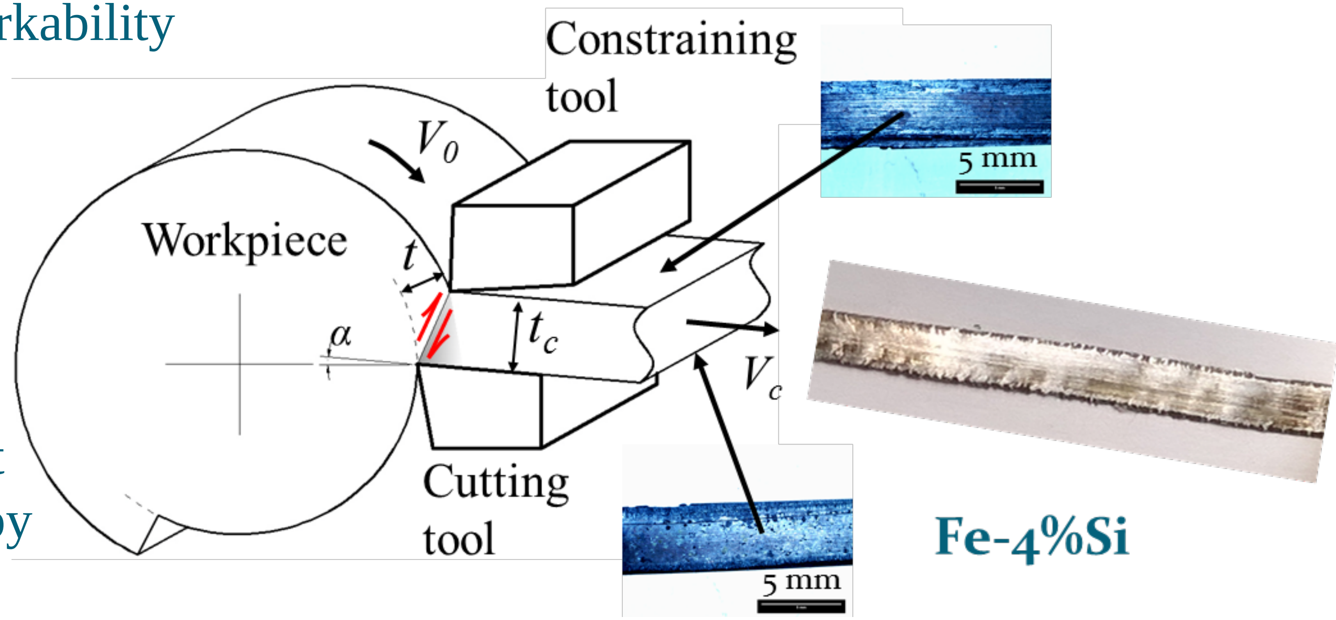
- High-Si steels: Need ~6 wt% Si to reach 80 μΩ-cm resistivity
  - Not cold-rollable above ~3.5% Si; cracking, low yields
  - Commercial 6.5% Si by diffusion-reaction of CVD Si-coated sheet, but $$$
  - Other routes historically, but none commercially successful

Technical Innovation

Hybrid cutting produces sheet and foil in a single stage of deformation, even from low-workability alloys, e.g., Fe-Si

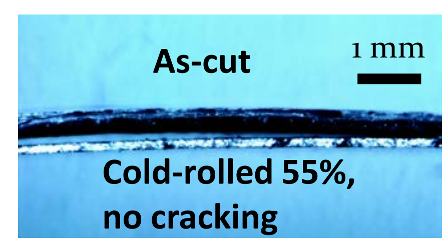
Unique deformation geometry: highly confined shear, temperature and hydrostatic pressure enhance workability

- Single-step production of sheet with compact infrastructure
- Shear-textured sheet is highly workable by rolling



Modified route: hybrid cutting + rolling also quite attractive

Side view



Technical Approach

- Tailor high-resistivity Fe-Si steel for hybrid cutting-extrusion

  Stage I: Rotary process configuration, up to 50 mm x 0.3 mm

  Process and sheet characterization

  Stage II: Based on results of Phase-I scaling (rotary or linear)

  Scale-up to 150 mm wide x 0.5 mm thick

- Multi-disciplinary team combining process and equipment design (Purdue and M4 Sciences) and materials characterization (Purdue and PNNL)
  - Complementary interaction with steel OEMs and tool/die mfrs.

Technical Approach

Risks and unknowns:

- Machine power constraints
- Workability limits for the high-resistivity alloys
  - Process limitation in shear banding/cracking at larger sheet cross-sections
  - Sheet quality attributes and stampability
  - Possible new (and controllable) shear textures

Unique Execution Attributes:

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

Results and Accomplishments

Milestones complete

M1.1 Two high-resistivity ternary alloys cast/rolled

Fe-3Si-3Al (78 μΩ-cm), Fe-4Si-4Cr (87 μΩ-cm)

M1.2 Critical feed rates for segmentation and strain upper boundary (workability) at 2-5 mm width

Al6013, Fe-1%Si, Fe-4%Si and exp. alloys

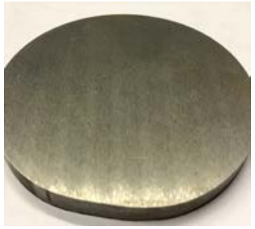
M1.3 Lower boundary for extrusion cutting and alloy selection for scale-up: Fe-4Si-4Cr

M2.1 Stage I process scaling machine installed

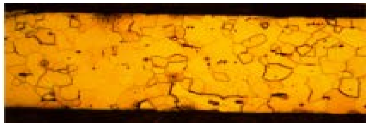
Results

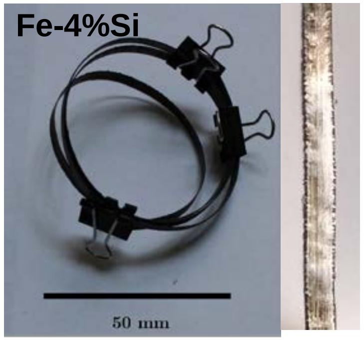
- New alloy for process scale-up
- Demonstrated 5 mm wide strips
- Characterized unique microstructure and texture
- Ready for Stage I scaling to 50 mm wide sheet
- Parallel process path identified
  - Hybrid cutting-extrusion/rolling and cutting-rolling
- Stage I equipment placed for hybrid cutting process

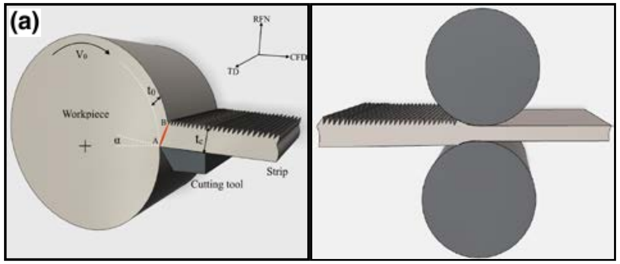
Fe-3Si-3Al ingot

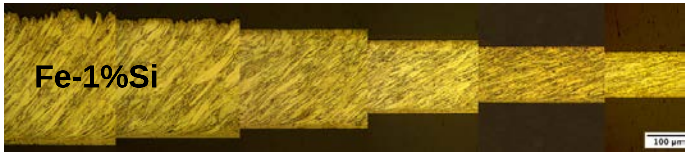


Fe-4Si-4Cr annealed









Transition (beyond DOE assistance)

2018-19 | 2019-20 | 2020-

Shear-based processing test-bed

IP Development

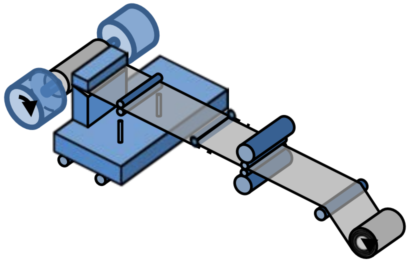
Pilot Production

Strategic Partner (SP)

IP Licensing/ JDA

Industry customer agreement by SP

Commercial production Fe-Si sheet by hybrid cutting/extrusion



- Strategy for transition by IP licensing with strategic partner (steel industry OEM)

Questions?