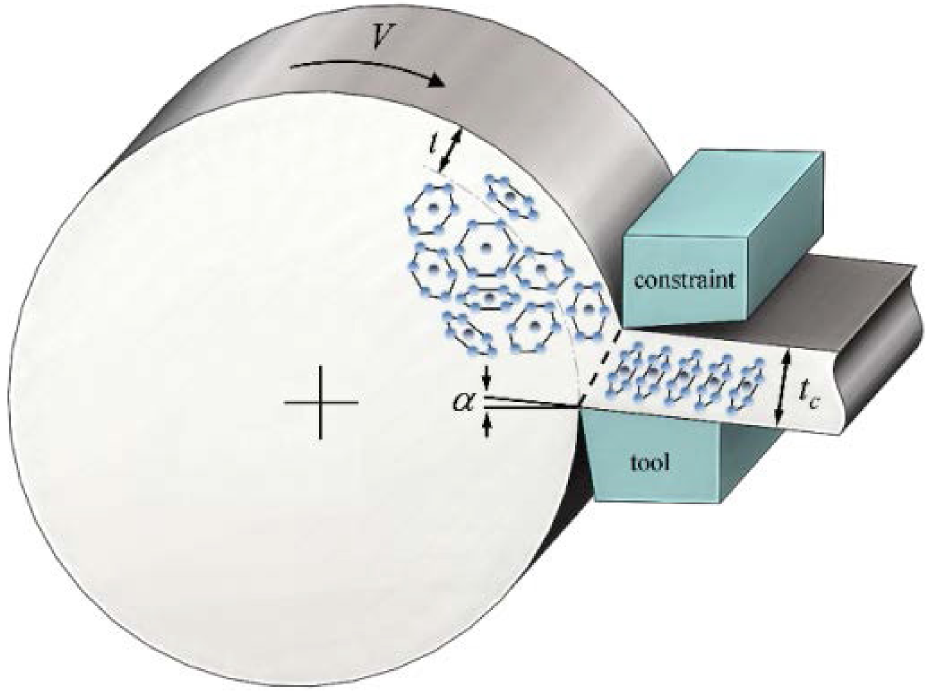
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY & RENEWABLE ENERGY

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

Novel manufacturing cutting-extrusion process enables production of steel alloy sheet for use in electric motor cores



The single-stage cutting-extrusion process to manufacture sheet metal has been developed at Purdue University. It has been used successfully at the laboratory scale to manufacture narrow strips of high silicon content steel. *Graphic courtesy of Purdue University*

Energy losses in electric motors can be divided into five major categories: core losses, windage and friction losses, stator losses, rotor losses, and stray load losses. In order to improve motor efficiency, these different types of losses need to be reduced. Core losses, which are caused by the magnetization of the motor core, are a significant portion of the total motor losses in partial load conditions and high frequency operation. To reduce core losses in a cost effective manner, inexpensive ways to increase the resistivity of soft magnetic materials need to be found.

Today, typical electrical steel used in motor cores contains 3.2% of silicon. Raising the silicon content of steel increases its resistivity, and at 6.5% silicon content it exhibits the best soft magnetic properties. However, such high silicon content makes the steel hard to cold roll—the most common way of producing sheet steel—without cracking. This project seeks to develop a promising new manufacturing approach to produce sheet from electrical steel with high silicon content. In the new approach, sheets of the steel alloy are produced in a single stage using a novel cutting-extrusion process. The new manufacturing technique has shown promise at the laboratory scale, but further research is needed to prove the concept.

Benefits for Our Industry and Our Nation

The single-stage cutting-extrusion process being developed is expected to consume only 25% of the energy used in a typical multistage rolling process to produce electrical steel sheet. The Department of Energy (DOE) estimates that the development of cost-effective soft magnetic materials with increased resistivity has the potential to reduce core losses in electric motors and generators by approximately 37%. Potential benefits from such efficiency improvement include:

- Energy savings of over 2,100 gigawatthours (GWh) per year in the industrial sector, or 0.37% of total energy annually consumed in industrial motors.
- Energy savings of 9,700 GWh per year in non-industrial motors, or 1.27% of total energy annually consumed by such motors.
- Energy savings of 0.44% of total United States electricity consumption.

Applications in Our Nation's Industry

The new material being developed and resulting higher efficiency motors will be suitable for a wide range of applications, including relatively slow speed, high torque density systems such as large commercial and industrial fans and manufacturing line conveyers. Moderate and high-speed applications, such as in-wheel motors in transportation systems, will also benefit from the new technology. Electronically controlled high efficiency motors for the blowers and fans used in the heating, ventilation, and air conditioning (HVAC) systems is the largest potential market for the new material and resulting motor designs. The improved motors will also be suitable for hermetic compressors used in HVAC systems.

Project Description

The project objective is to develop and demonstrate a single-stage, cutting-extrusion manufacturing process to produce sheet of steel alloy with high silicon content. The first phase of the project will focus on identifying alloy compositions that meet the mechanical, electrical, and magnetic requirements to significantly reduce electric motor core losses. After two suitable alloy compositions are identified, a manufacturing process to produce electrical steel sheet 150 mm wide x 0.5 mm thick will be developed.

Barriers

- Higher silicon content of electrical steel reduces its ductility and workability, making it difficult to process without cracking.
- Developed cutting-extrusion process may cause unforeseen changes in the characteristics and performance of the steel alloy.
- Ability to scale may be limited by lack of sufficient machine power and tooling design.
- Significant existing investments in rolling mill infrastructure is likely to slow the acceptance of the new cutting-extrusion process.

Pathways

In the first phase of the project, project team researchers will identify two suitable high silicon content steel alloy compositions for process development. In evaluating different alloys, their mechanical, electrical, and magnetic properties, as well as microstructure, will be characterized. The developed alloys need to have high resistivity—at least 80 microohm-centimeter (μΩ-cm)—and good mechanical properties that make them suitable for electrical steel sheet production.

The cutting-extrusion manufacturing process development will be done in two stages, with the ultimate goal of producing electrical steel sheets that are 150 millimeters (mm) wide and 0.3-0.5 mm thick. The manufacturing method being developed—which has been successfully used to manufacture sheets of other materials with similar manufacturability challenges—produces a steel sheet in a single stage of deformation, making it an energy efficient and, potentially, very cost-effective processing method.

Manufacturing equipment for the cutting-extrusion process will be designed and built. Project partners experienced with tooling development will assist the Purdue team with this task, as well as with process optimization.

Milestones

This 3-year project began in 2017.

- Identify two suitable high silicon content steel alloy compositions for process development (2018).
- Develop the cutting-extrusion process to produce high silicon content electrical steel sheet of 50 millimeters (mm) in width and 0.3-0.5 mm in thickness (2018).
- Design and build equipment for the cutting-extrusion process (2019).
- Produce high silicon content electrical steel sheet of 150 mm in width and 0.3-0.5 mm in thickness (2020).

Technology Transition

Electrical steel sheet used in induction motor cores is currently manufactured using a multistage process involving hot and cold rolling, and annealing operations. These processes are energy intensive, require significant investment in infrastructure, and cannot be used to produce sheet steel with high silicon content. The developed single-stage cutting-extrusion process can produce high silicon content steel, and the technology has the potential to substantially lower manufacturing cost. With this significant market potential, two major American steel manufacturers have expressed interest in advancing the technology.

Project Partners

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