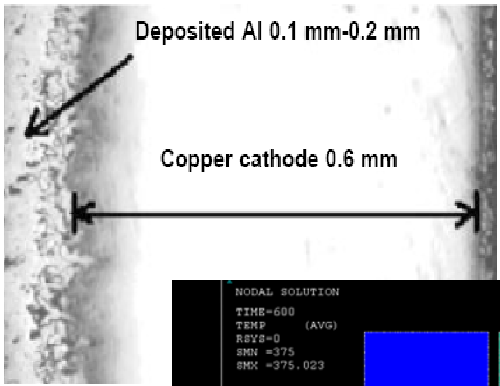
Industrial Technologies Program

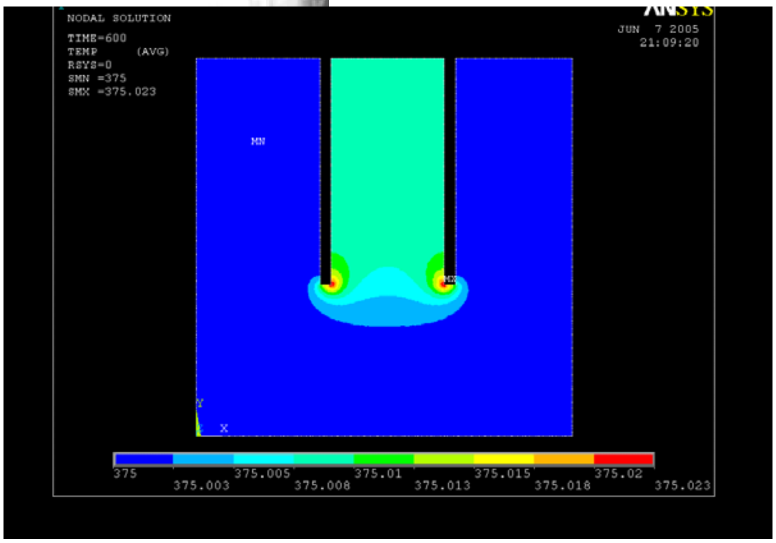
Low-Temperature Reduction of Alumina Using Fluorine-Containing Ionic Liquids

Future Alternative to Displace Existing Hall-Héroult Technology

Aluminum is produced by the electrochemical reduction of alumina (aluminum oxide). The Hall-Héroult process, developed in 1886, is the only commercial method for production of aluminum. This electrolysis process uses molten cryolite (sodium-aluminum fluoride) as the electrolyte to dissolve alumina and is highly energy intensive. Currently the most efficient U.S. primary aluminum production technologies require about 15 kilowatt hours per kilogram of aluminum (kWh/kg Al), while the theoretical minimum energy requirements for the Hall-Héroult electrolysis is approximately 6 kWh/kg Al. The U.S. facilities are thus operating at roughly 40 percent energy efficiency. The high energy consumption of this process is mostly due to the high temperature (900-1000^{o}C) required to maintain the cryolite bath molten for electrolysis. Despite its high melting point, no suitable substitute has been found for cryolite. The project team saw the opportunity to save significant amounts of energy by substituting room temperature ionic liquids as the electrolyte to produce primary aluminum and electro-refine aluminum scrap. The project demonstrated the feasibility of low-temperature electrolysis in the range of 25 to 110^{o}C. Energy consumption for the electrolysis using ionic liquids is projected to be in the range of 9.5 to 10.5 kWh/kg, which is 30 to 37% lower than energy consumed by the current technology. This R&D has the potential to displace the Hall-Héroult process and save significant energy for the U.S. aluminum industry.



Electrodeposited aluminum on a copper substrate obtained using chloride-based ionic liquids as electrolytes



2D Electrothermal Analysis of Electrolysis Cell

Benefits for Our Industry and Our Nation

- Potential energy savings of about 99 trillion Btu per year by 2025
- Potential cost savings of about $580 million per year by 2025
- Reduction of green house gas emissions
- Reduction of fluoride emissions

Applications in Our Nation's Industries

The development of a low-temperature process for the production of primary aluminum is one of the major challenges that the aluminum industry faces today. The successful results of this research demonstrated that alternative approaches are possible. This development could strengthen the position of the domestic aluminum companies in an increasingly competitive global aluminum marketplace.

Project Description

The goal of the project was to demonstrate a low-temperature reduction process for the production of primary aluminum using chloride ionic liquids. This technology has the potential to be an alternative process to the conventional Hall-Héroult process.

Barriers

Intense experimentation and the expertise of the R&D team were used to overcome the initial technical hurdles:

- Lack of ability to synthesize different chloride-based ionic liquids
- Lack of ability to enhance the electrical conductivity of the ionic liquids using appropriate additives
- Lack of ability to perform electrolysis experiments in controlled atmospheres due to moisture sensitive electrolyte

Pathways

The objectives of this project were to

- synthesize chloride-based ionic liquids for the electrolytic reduction of aluminum at low temperatures
- reduce aluminum from aluminum chloride ($AlCl_3$) using chloride ionic liquids at low temperatures
- electro-refine aluminum scrap using chloride ionic liquids at low temperatures
- carry out detailed evaluation and optimization of the experimental variables involved in the electrolytic process
- evaluate the physical, thermal, and thermodynamic properties of the electrolyte
- evaluate the morphology, structure, and chemical composition of aluminum deposits using various characterization techniques
- compare costs, processing issues and performance of the new reduction and refining process

Milestones

The accomplishments obtained include the following:

- Synthesized alternative ionic liquids
- Characterized ionic liquids and studied their thermal electric and dynamic properties
- Conducted laboratory experiments including Al-MMC anode recycling in ionic liquids, laboratory electrolysis in ionic liquids, batch recirculation electrolysis, and pilot electrolysis
- Developed mathematical modeling of aluminum electrolysis in ionic liquid electrolyte

Future milestones that remain to be accomplished are as follows:

- Investigate the feasibility of electrolysis of aluminum in sulfate and fluoride ionic liquids
- Determine the feasibility of scaling-up the process of electrolysis in ionic liquid electrolytes to 5-10 liters scale batch process

Commercialization

The project developed fundamental knowledge. Its commercialization will only be realized through additional research and development. The knowledge developed during the project was transferred to the participating companies. The companies participating in the project have a clear and direct interest in expanding the R&D work of the program.

In the past century, there have been a number of attempts at alternatives to the Hall-Héroult process. Several alternatives have been developed to near industrial scale, but abandoned because of technical problems and lack of overall economic advantage over the Hall-Héroult process. Thus the Hall-Héroult process remains to be displaced commercially.

Project Partners

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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

U.S. Department of Energy
Energy Efficiency
and Renewable Energy

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