U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Energy Efficient Thermoplastic Composite Manufacturing

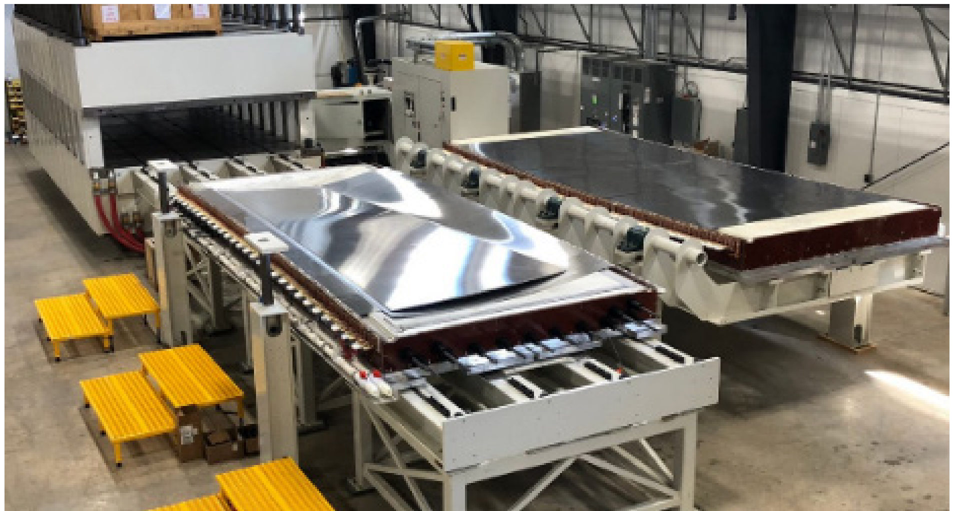

Figure 1. Above is a photo of the equipment and tooling built during this project, including the aluminum bladder on the lower tool (foreground left), the upper tool (foreground right), and the restraint section where the thermal induction processing occurs (behind the lower tool).
Photo courtesy of The Boeing Company

Composite aircraft structures have been shown to enable lightweight, efficient designs. However, the extended thermal cycles needed for existing methods and materials makes them less attractive for higher-rate production applications.

Current manufacturing systems, such as autoclave processing of thermoset materials, require long cycle times due to the method of heating and large thermal masses. These elongated cycle times, while effective for lower rate applications, inhibit the ability to meet forecasted high-rate production scenarios due to the need for multiple sets of equipment and tools.

Alternatively, thermoplastic composite materials facilitate more rapid cycle times by eliminating the need for a long cure dwell time at temperature. Furthermore, induction heating can heat materials very quickly and efficiently, especially when coupled with low thermal mass tool designs. Since this processing method only heats a very small portion of the tool for the consolidation and molding of thermoplastic components, there is a significant opportunity for increased energy efficiency over resistive, conductive, and convective heating of an entire tool.

This project successfully demonstrated and documented the energy efficiency and technical and economic viability of induction consolidation using smart susceptors for full-scale integrated thermoplastic composite structures in an aerospace application. Smart susceptor technology will enable large-part fabrication using induction heating and advanced coil designs, since thermal control is no longer an issue. The project leveraged intrinsic thermal control to provide rapid, precise heating for both consolidation and joining.

Benefits for Our Industry and Our Nation

Induction consolidation of thermoplastic composites using smart susceptors can significantly reduce the cycle time and energy used for manufacturing.

This project successfully demonstrated process energy savings of more than 90% compared to typical autoclave processing. The rapid cycle times resulted in more affordable and efficient fabrication of composite aerospace structures at accelerated rates of production. The increased integration of lightweight composite components into aerospace applications will also reduce fuel consumption and carbon emissions throughout the useful life of aircraft.

Applications in Our Nation's Industry

With many markets transitioning to lightweight composites for performance gains, the use of these components is increasing. The processing technology developed here has broad application to a number of industries in addition to aerospace including wind, automotive, marine, and heavy trucks. Implementing efficient production methods that enable significant energy savings and improved manufacturing processes keeps the United States globally competitive.

Project Description

The project achieved its objective to establish an effective and affordable method to layup and consolidate large thermoplastic composite aerospace structures with thermal cycles measured in minutes to a few hours rather than many hours. This project demonstrated and documented the viability of induction consolidation using smart susceptors for full-scale integrated thermoplastic composite structures in aerospace applications. The built component demonstrated an improved capability to meet high production rates for large aerospace thermoplastic composite structures and validated the ability to precisely control temperatures required to consolidate the part with improved energy efficiency.

Barriers Addressed

- Cost of switching from thermoset materials to thermoplastic materials
- Achieving scale-up needed to be relevant in the aerospace and other industries

Pathways

Project partners used predictive modeling and simulation of the processes in conjunction with validation through fabrication of mid-scale components to establish system scalability and reduce project risk. This validation compared the predicted values of factors such as current levels, power usage, and thermal distribution measured during the processing of the scale-up components.

Full-scale designs of the machines and tools required to meet both the rate and the general size for aerospace industry were then developed. Full-scale candidate components were fabricated using the rapid, energy-efficient induction processing technology. A representative candidate component with potential near term economic benefit was selected and then developed.

The project further quantified the existing energy used in standard heated autoclaves and compared these values to the new process as well as quantifying the lifecycle energy costs of materials being replaced.

Milestones Completed

This project began in 2015 and was successfully completed in June 2019.

- Demonstrated complex part consolidation with less than 120 minutes processing time and 40% reduction in energy consumption compared to autoclave processing
- Established and integrated a fabrication system capable of processing a large (5 ft. by 15 ft.) component scale-up demonstration
- Consolidated a large, complex component with improved thermal uniformity with demonstrated potential of less than 60 minutes processing time and 80% reduction in energy consumption compared to autoclave processing

Accomplishments

- Validated rapid heat-up and cool-down rates for consolidation of large thermoplastic skins with precise thermal control and even pressure application at the consolidation temperature (Figure 2)
- Verified energy savings of 90% for rapid consolidation of large thermoplastic composite components using induction consolidation with smart susceptors compared to autoclave processing, the current baseline method for curing composite materials
- Assisted in de-risking the establishment of high-rate composite structures fabrication capability through rate insensitivity
- Will enable affordable and efficient high-rate production of large composite aerospace structures when successfully developed

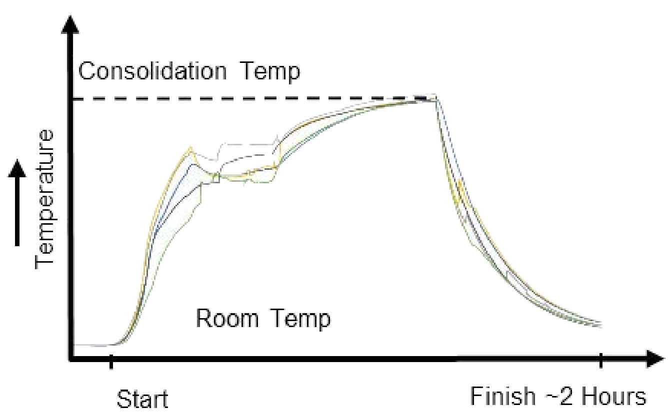

Figure 2. A thermal profile performed during consolidation of a thermoplastic preform. Note the rapid heat-up rate, precise leveling of the temperature at the consolidation temperature, and the rapid cool-down rate. The elongated hold before the final ramp to temperature may not be necessary for a successful consolidation cycle.
*Figure courtesy of **The** Boeing Company*

Technology Transition

While many factors influence the materials and processes utilized for airplane manufacturing, an accelerated production rate forecast and recent performance successes of composites in airplane construction provide an opportunity for this processing technology to have significant influence. The Boeing Company has a key leadership position within the aerospace industrial community. All project partners have extensive commercialization knowledge and experience in their own market segments and will ensure a supply base for equipment and tools for the infrastructure is in place and readily available to all potential industrial users.

Project Partners

The Boeing Company
Seattle, WA
Principal Investigator:
Marc R. Matsen
Technical POC: Brandon Gorang
brandon.p.gorang@boeing.com

Cytec Engineered Materials
Anaheim, CA

Ajax
TOCCO
Warren, OH

Temper, Inc.
Rockford, MI

For additional information, please contact

Steve Sikirica
Technology Manager
U.S. Department of Energy
Advanced Manufacturing Office
Phone: (202) 586-5041
Email: *stephen.sikirica@ee.doe.gov* ■

Project final report available at *www.osti.gov/scitech: OSTI Identifier 1609100*

U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

For more information, visit:
energy.gov/eere/amo

DOE/EE-1871 · June 2020