U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Rapid Freeform Sheet Metal Forming Technology Development and System Verification

The RAFFT machine built in the first year of the project is on the left. On the right is a 0.4 scale Mustang hood, still in the machine clamp, formed using the RAFFT machine. *Photo credit Ford Motor Co.*

The automotive, aerospace, and appliance industries use sheet metal forming processes that deform an initially flat sheet of metal into a final three-dimensional shape. A traditional sheet metal stamping process utilizes a set of dies under mechanical force generated by a press to deform the metal sheet. The process is highly effective for high-volume, mass production, with a typical cycle time of less than 10 seconds. However, when production volume is lower, for example, fewer than 1,000 parts, the traditional stamping process, while still used, becomes less attractive with regard to time, energy, and cost since the large die sets have to be engineered, cast, machined, and then tested. Aircraft manufacturers often avoid the construction of dies altogether by directly machining semi-finished pieces of metal. However, this process may waste up to 95% of high grade aluminum alloys used by the aerospace industry.

This project developed a new manufacturing system for small volume, on-demand production called RApid Freeform Sheet Metal Forming Technology (RAFFT). The core technology in RAFFT is Double Sided Incremental Forming (DSIF), a new concept for sheet forming in which a sheet blank is clamped around its edges and gradually deformed by two strategically aligned stylus-type tools that follow programmed toolpaths. The two tools, one on each side of the sheet blank, can form a part with both concave and convex shapes as well as detailed features. The tools have multiple degrees of freedom, and can be independently controlled or synchronized to achieve desired shapes.

Benefits for Our Industry and Our Nation

By eliminating the need for stamping dies (and their associated heavy machinery and presses), the benefits of RAFFT for making prototypes, small volumes, or on demand customized sheet metal parts include:

- Shortening typical cycle times for sheet metal forming from 4–16 weeks to less than 1 week, which significantly improves the design cycle
- Reducing energy consumption by 50–90% compared to stamping, hydro-forming, or superplastic forming
- Opportunities to significantly reduce material scrap by increased materials utilization efficiency
- Reducing inventories for replacement parts and/or dies
- Reducing total cost of low volume production by up to 90%

Applications in Our Nation's Industry

The RAFFT technology has applications in a number of industries that rely on the manufacturing of sheet metal products. The technology can benefit small businesses with custom products; prototyping and customization in the automotive and appliance industries; regular production and on-site repair for civilian and military aircraft components; and applications in biomedical and point-of-need products.

Project Description

This project developed RAFFT in an industrial environment based on DSIF, a process that eliminates the need for geometric-specific forming dies. The system has an effective working sheet area of 2.0 meters x 1.5 meters (6.5 feet x 5 feet), allowing for the forming of a wide range of sheet metal parts used in automotive and aerospace applications. Researchers successfully demonstrated the technology by producing an aluminum hood outer for a current production automobile. Industrial parts were produced within one week of receiving engineering computer-aided design (CAD) data while also satisfying a set of production metrics including dimensional accuracy, surface finish, and cycle time. The project was technically challenging, requiring the development of efficient algorithms to rapidly generate toolpath programs.

Barriers

- Achieving the required stiffness, accuracy and consistency
- Toolpath generation algorithms for complex shapes and features required to achieve dimensional accuracy, cycle time and surface finish while accounting for springback, in-process part distortion, and multi-feature interactions
- Real-time process control for the RAFFT system

Pathways

Project partners built upon previous research in order to design and build an industrial-scale RAFFT system. The system includes a reconfigurable clamping design for handling and holding the sheet blank, a system controller for synchronizing tool motions, and advanced forming tools with reduced friction and improved surface finish. The toolpath generation algorithms developed include single- and multiple-stage forming strategies for complex geometries.

The system is integrated with process control software and toolpath generation algorithms for multi-stage forming. Successful integration of the system was demonstrated by making an aluminum alloy hood outer within one week of receiving part CAD data while also meeting tolerance and surface finish requirements.

The project included a lifecycle analysis comparing RAFFT with competing processes such as stamping and superplastic forming. Metrics include number of parts produced, energy use, carbon equivalent, waste quantities, and cost. Analysis by the MIT team will guide optimal applications of RAFFT for energy and cost.

Milestones

This project began in 2013 and completed successfully in 2017. In the first year of the project, Ingersoll was selected through a competitive process to design and build the RAFFT system.

- Manufactured and assembled the industrial-scale RAFFT system to meet design specifications for stiffness, accuracy and consistency
- Validated an automated DSIF toolpath generation process by manufacturing a series of complex freeform parts
- Demonstrated successful integration and validation of the RAFFT system with process control software by making an aluminum alloy hood outer
- Documented and validated energy and cost models using available data for RAFFT and three other sheet forming processes used in both the automotive and aerospace industries

Accomplishments

- Developed, integrated and verified a RAFFT machine that can form sheet metal parts without using dies. The prototype machine has the potential capability of making the majority of sheet metal parts used in ground and aerospace applications.
- Developed, implemented, tested, and released new algorithms for generating DSIF toolpaths in the RAFFT software. In addition, a platform for exchanging data among all software applications was developed and is being used for modeling, analysis and testing.
- Identified specific areas where RAFFT can replace conventional technologies through Energy Management and Environmental Impact Modeling.

Technology Transition

Ford proposes transitioning the technology in several phases. RAFFT technology will be implemented at Ford New Model Programs Development Center, which provides stamping engineering and produces prototype products for Ford. During this phase, RAFFT will be integrated into a complete sheet metal prototyping ecosystem that includes trimming, hemming, flanging and joining. Panels will initially be supplied internally to Ford, and then the focus will be on external commercialization via licensing the RAFFT software applications and machine specifications.

Project Partners

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The Final Report is available at *www.osti.gov/scitech: OSTI Identifier 1433826*

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