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Modular Hydropower Engineering and Pilot Scale Manufacturing

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ABSTRACT

Emrgy has developed, prototyped and tested a modular hydropower system for renewable energy generation. ORNL worked with Emrgy to demonstrate the use of additive manufacturing in the production of the hydrofoils and spokes for the hydrokinetic system. Specifically, during Phase 1 of this effort, ORNL printed and finished machined patterns for both the hydrofoils and spokes that were subsequently used in a sand casting manufacturing process. Emrgy utilized the sand castings for a pilot installation in Denver, CO, where the parts represented an 80% cost savings from the previous prototype build that was manufactured using subtractive manufacturing. In addition, the castings were completed with ORNL's newly developed AlCeMg alloy that will be tested for performance improvements including higher corrosion resistance in a water application than the 6160 alloy used previously.

1. MODULAR HYDROPOWER ENGINEERING AND PILOT SCALE MANUFACTURING

This phase 1 technical collaboration project (MDF-TC-2017-112) was begun on April 12, 2017 and was completed on July 30, 2017. The collaboration partner, Emrgy is a small startup business. Two patterns were designed and fabricated for use by Eck Industries, Inc. in fabricating hydrofoil blades and spokes using sand castings.

1.1 BACKGROUND

Emrgy is a small, woman-owned startup company (2014) that has developed modular hydrofoils to be installed in man-made canals for hydrokinetic renewable energy generation. Standardized modular hydropower technologies represent an emerging renewable energy source that combines the high reliability and availability attributes of hydropower with the scalability and rapid growth potential of other modular technologies. The successful deployment of modular hydrokinetic systems will reduce the technological and economic barriers to new hydropower capacity by enabling efficient manufacturing, reducing infrastructure requirements and streamlining deployment times. The potential for continuous, baseload energy generation is a breakthrough for modular renewable equipment and will increase economic competitiveness of renewable generation and cost-effectiveness of investments by reducing payback periods.

The challenge addressed by this effort was to identify and verify potential fabrication methods that can increase the Technology Readiness Level (TRL) and improve the performance and cost-effectiveness of the system. Success will be measured by the improvements in these parameters.

During Phase 1, the team collaborated to address Emrgy's manufacturing challenge of producing hydrofoils and spokes in a short time frame for pilot installation. The success metric for Phase 1 is manufacturing speed and cost. As a small company, Emrgy was prototyping using subtractive manufacturing, which is costly and time consuming. The team proposed to utilize additive manufacturing to produce patterns for sand castings that could increase the speed of production as well as reduce costs. This approach was also believed to be able to maintain or improve system performance through the use of ORNL's newly developed AlCeMg alloy in the castings.

Through the Technical Collaboration in Phase 1 Emrgy was able to produce all 54 hydrofoils and 54 spokes needed for pilot installation in 1 day of casting at 80% cost savings per part over subtractive manufacturing.

1.2 TECHNICAL RESULTS

The initial plan was to fabricate the hydrofoil out of reinforced polymer composite material. Instead, to address design changes, estimated loads and to accommodate the build schedule for the Denver pilot demonstration, it was decided that using additive manufacturing to make patterns for sand casting of the hydrofoils and spokes out of cerium-aluminum alloy was the best approach for Phase 1. Eck Industries Inc., the casting specialist that Emrgy was working with, provided ORNL with models with the gating added to the Emrgy designs and is the licensee for the ORNL AlCeMg alloy.

From the Eck models, ORNL designed an integrated pattern and pattern box that was printed out of ABS with 20% carbon fiber on ORNL's BAAM (Big Area Additive Manufacturing) printer. The box and pattern design included material added to support overhangs. The extra material as well as the pattern surface and the inside edges of the patter box were to be machined to yield a smooth surface for the casting. Both the cope and drag pattern boxes (Fig. 1) were printed and weighed in excess of 500 lbs each. The design of the integrated box and pattern did not allow for sufficient access for the machine head of the router. Machining was aborted and it was decided, due in part to schedule constraints, to print the patterns without the integrated box. All four patterns, cope and drag for both the hydrofoil and spokes, were printed simultaneously in a single build. The four patterns are shown in Fig. 2 while still on the printer.

Fig. 1. Integrated pattern and pattern box, cope and drag.

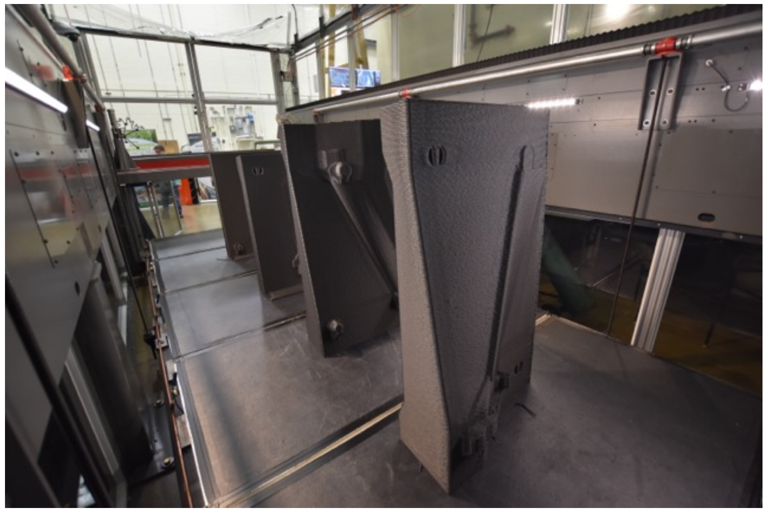

Fig. 2. Printed hydrofoil and spoke patterns, cope and drag.

Both spoke patterns are shown in Fig. 3 and the hydrofoil drag pattern in Fig. 4. Both figures show the patterns as printed. Machining of the patterns was performed on a Thermwood Multipurpose 5-Axis CNC Router.

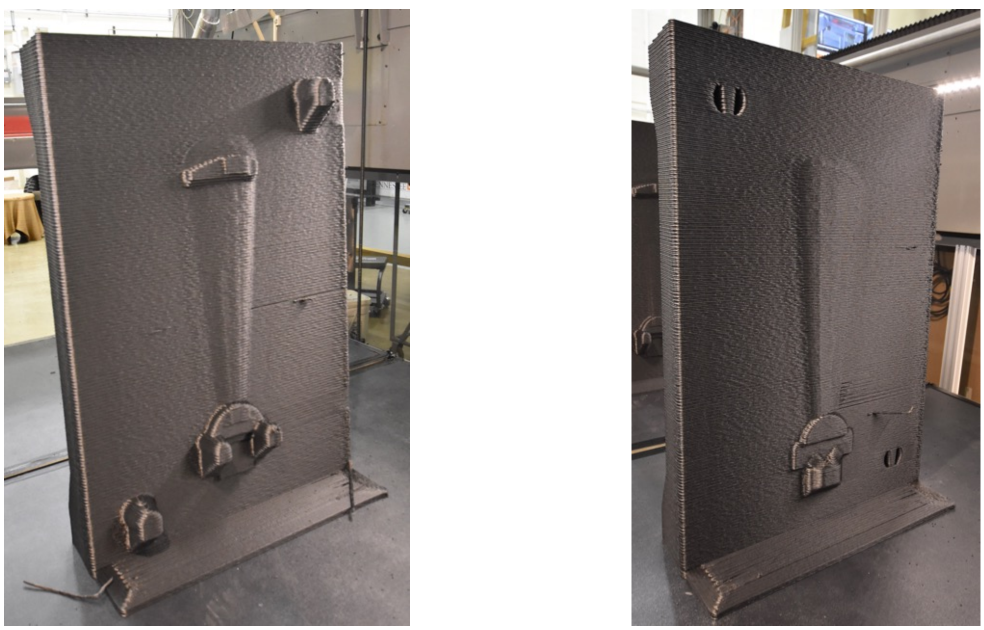

Fig. 3. Printed spoke patterns, cope and drag.

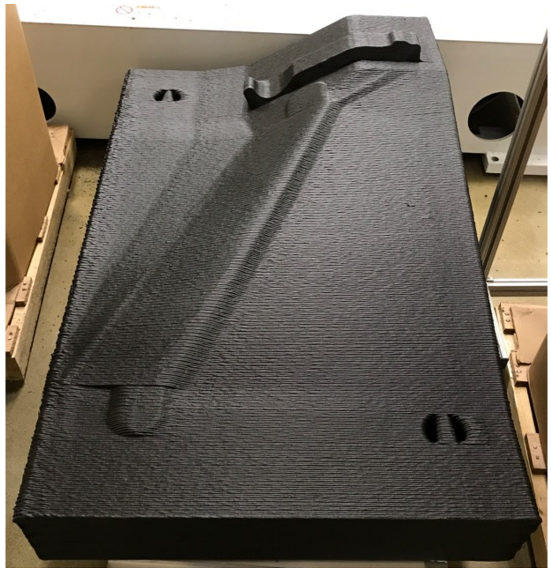

Fig. 4. Hydrofoil drag pattern, prior to machining.

The printed patterns were shipped to Eck Industries. Eck smoothed out minor defects with an automotive body putty, coated it with a heavy fill automotive primer and coated with an automotive lacquer. Patterns for the hydrofoil are shown in Fig. 5. After preparing the surface, plywood was used to form the pattern boxes around the pattern.

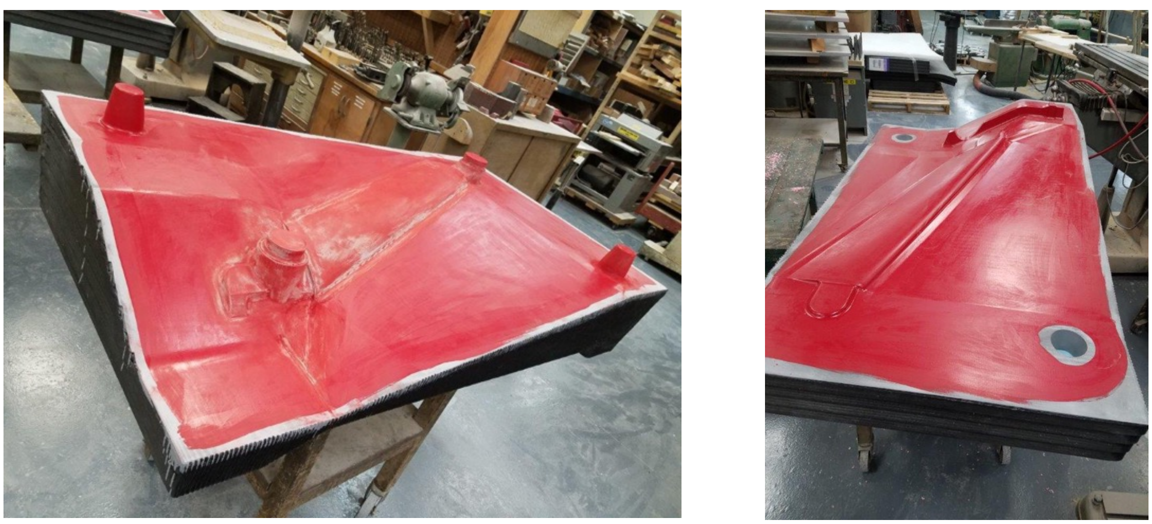

Fig. 5. Hydrofoil cope and drag patterns prepared at the pattern shop.


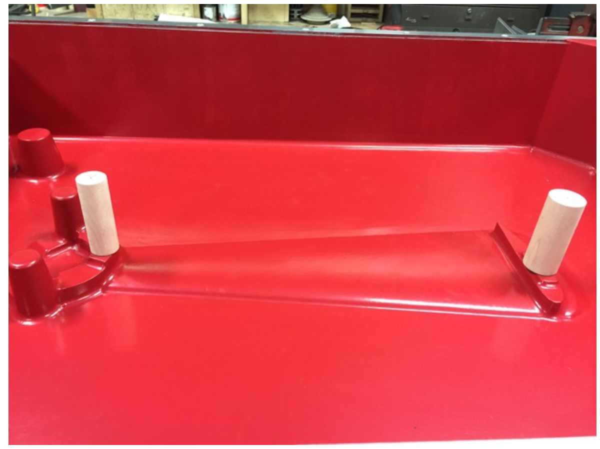

Fig. 6. Hydrofoil and spoke pattern and pattern boxes.

The pattern boxes were used to make castings for the Denver Water demonstration. Shown in Fig. 7 are a single hydrofoil and multiple spokes. The hydrofoil still has flashing on it and has not been cleaned up. The spokes are shown as they came out of the sand casting process prior to removal of the casting artifacts.

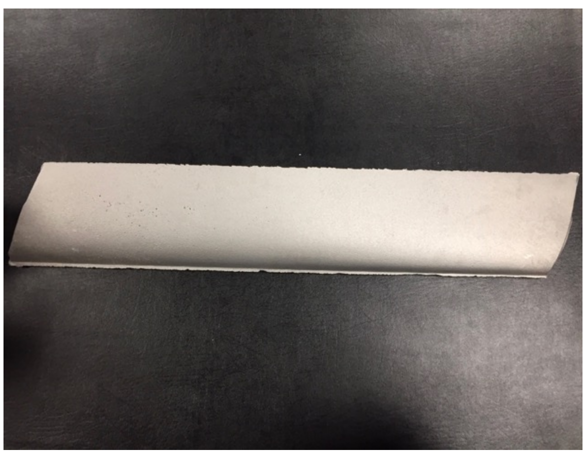
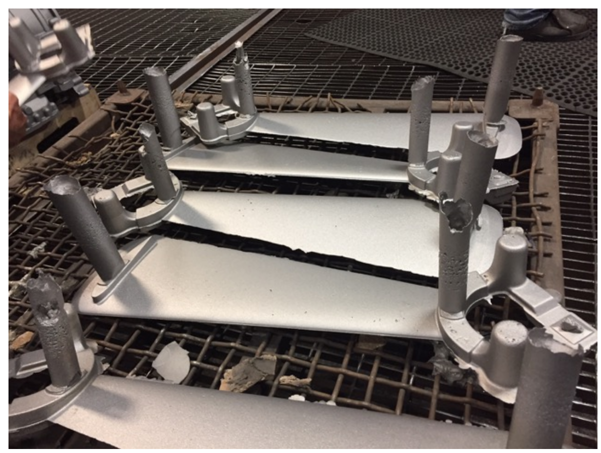

Fig. 7. First hydrofoil casting and spoke castings.

1.3 IMPACTS

Emrgy Inc. has developed, prototyped and tested a design for modular hydrofoils to be installed in manmade canals for hydrokinetic renewable energy generation. This design is being manufactured for an array pilot project in conjunction with Denver Water, the National Renewable Energy Laboratory and the US Bureau of Reclamation, in which ten of Emrgy's modular hydropower turbines will be installed within approximately 1000 feet of a 9-mile long canal in Denver. The technology is believed to be scalable not only throughout the rest of the canal in Denver, but also to thousands of miles of canals throughout the United States.

In this collaboration, the next generation of additive manufacturing equipment was used at ORNL to build modular hydrofoils that are cost effective, rapidly producible and able to optimize the fluid dynamics and wake effects observed in kinetic generation arrays to efficiently extract energy from a moving waterway and convert it into electric power.

Successful, modular approaches to rapidly deployable hydrokinetic power units will represent a strategy for cost effective renewable energy generation, leading to commercialization of a new distributed energy resource. The prototype components constructed in this Technical Collaboration will be pilot tested in 2017, and in fact the parts produced during Phase 1 have already been installed in the Denver Pilot. If successful, this Technical Collaboration will increase the Technology Readiness Level (TRL), onboard new customers and grow the production of continuous, reliable renewable energy in the United States.

Fig. 8. First set of casted parts being installed in the Denver pilot.

Fig. 9 Prototype 1 and Prototype 2.
Prototype 1 (subtractive) in background. Prototype 2 (TC-casted) in foreground.

1.4 CONCLUSIONS

Patterns were 3D printed and machined to fabricate blades and spokes for a series of ten units to be installed in a canal in Denver for Phase 1. The objective was to demonstrate the cost-effective manufacturing of these parts. The cost of the finished blades and spokes were $265 and $205 respectively. Compared to the subtractive manufactured approach taken for the first prototype in which finished blades and spokes cost Emrgy $1175 and $1065 respectively, Phase 1 of this Technical Collaboration has resulted in 78% cost savings per part for Emrgy. These parts are being put into service as part of the demonstration project. Phase 1 successfully demonstrated the use of Additive Manufactured patterns to cost-effectively produce parts for use in a hydrokinetic renewable energy generation application.

Phase 2 will focus on the use of composite fabrication techniques to make optimized, cost-effective blades and spokes. This approach will enable Emrgy to not only continue to improve cost and production speed, but also test possible performance improvements and/or durability of composite components for hydrokinetic applications. The appropriate molds will be fabricated using the Metal-BAAM system, and pilot tested in 2017-2018 so that comparative data can be gathered and analyzed.

2. PARTNER BACKGROUND

Emrgy, founded in 2014, is a transformational technology company that enables customers to generate electricity from slow or shallow water flows to offset energy consumption or achieve grid power independence.

Together with the US Department of Energy and US Office of Naval Research, Emrgy developed a compact, portable hydropower turbine based on a proprietary magnetic gear that overcomes the compromises of conventional turbines plagued by the risks and limitations of mechanical gears, representing a breakthrough in kinetic power conversion. It has been selected as one of the Top 30 Emerging Technologies by the National Renewable Energy Laboratory.

Emrgy's SUV-sized turbines convert energy in moving water to 10KW of renewable electric power. The devices integrate directly within continuously flowing waterways to harvest energy around the clock – each device potentially amassing over 200kWh in a single day. Compared to wind and solar alternatives, Emrgy produces 2-3X the energy for the same rated power capacity.

Each $40,000 device produces the energy equivalence of 7 average US homes, 42 in Germany, or 86 in India.