ORNL Manufacturing Demonstration Facility
Technical Collaboration **Final Report**

Advanced Manufacturing of Complex Cyber Mechanical Devices through Community Engagement and Micro-manufacturing [1]

Local Motors Inc.

Project ID:	MDF-TC-2014-040
Start Date:	1/24/2014
Completion Date:	4/19/2014
Company Size:	Small business

Summary
This project demonstrated the integration of components onto a prototype body part for a vehicle. The project demonstrated that it is possible to use ORNL's Big Area Additive Manufacturing (BAAM) system to manufacturing vehicle body parts with attachment fixtures suitable for automotive applications.

Background
A key element to Local Motors' (LM) business model is the ability to rapidly manufacture lightweight, highly customized electric vehicles. This project was necessary to demonstrate the ability to rapidly manufacture a custom vehicle. ORNL's BAAM technology enables the direct digital manufacture of complex structures very rapidly (targeting manufacturing a 500 lb vehicle body in under two days). The goal is massive part consolidation to enable the development of an electric vehicle with using less than 30 parts. The first phase of this project focused on key enabling technologies such as quantifying the mechanical strength of the materials and integration of fasteners into the structures. The team successfully demonstrated the ability to manufacture a subsystem of the vehicle and conducted load testing to validate the integrity of the materials and structure.

Technical Results
Prior work on large scale polymer additive manufacturing demonstrated the ability to rapidly manufacture large polymer structures using ORNL's Big Area Additive Manufacturing system (BAAM) (see Figure 1). Prior work in filled materials (see Figure 2) enables "out-of-the-oven" additive manufacturing. By working out of the oven, it enables integration of other components onto the system. As an example, it is possible

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to integrate a machining head (see Figure 3) onto the BAAM to enable fine surface finish and details.

Figure 1: Big Area Additive Manufacturing

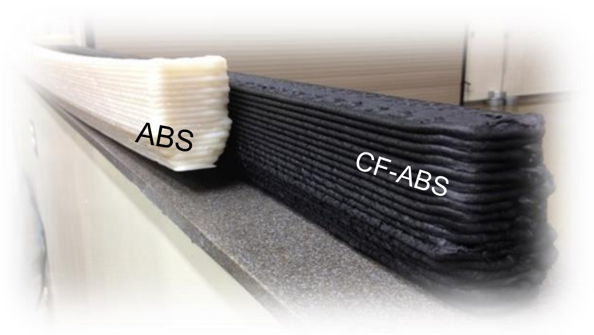

Figure 2: Impact of filled material

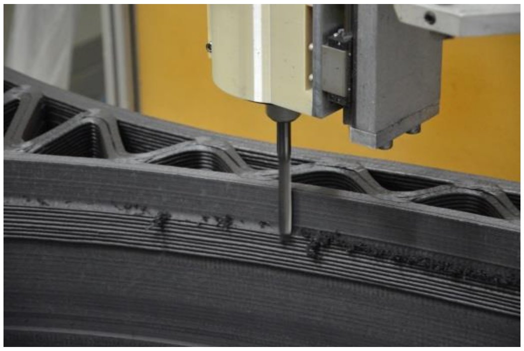

Figure 3: Integrated Machining

In order to develop a system with integrated components, there were two fundamental tasks executed during this investigation. First, the team focused on manufacturing components with over hangs. A variety of support structures were evaluated. Support structures included a pellet bed (see Figure 4) where the parts were surrounded by unmelted pellets, movable fixtures and break away supports. The unmelted pellets proved difficult to use due to the movement of the material during extrusion leading to poor accuracy in deposition. Movable fixtures consisted of emplacing fixtures into the workplace for support, then removing after the build is complete. This process works extremely well but requires hands on operations. The final approach was break away support. This approach worked best. A support structure was designed into the structure (the front right quarter body wheel well in Figure 5) then removed after the build was complete.

Figure 4: Pellet bed support

Figure 5: Break away support

Figure 6: Threaded insert

The second task focused on attachments. When making a system, mechanical elements (motors, sensors…) must be attached to the body. There are a number of different ways to attach parts to the structure. One approach is to drill and tap holes into the material. However, it was found that the threads were relatively weak and could strip over time. The method that showed the greatest promise was threaded inserts (see Figure 6). A pilot hole is drilled in the plastic body then the insert is heated with a solder iron and pressed into the structure. The material around the insert melts and flows into the insert giving an extremely strong bond. Samples were manufactured using ¼-20 threaded inserts and pulled to measure the holding strength. The polymer has a yield strength of approximately 10 ksi. The inserts pulled out between 1145 and 1355 lbs. A ¼-20 bolt has a stress area of 0.031 in^2. Therefore, the yield stress is between 37.0 ksi and 43.7 ksi, comparable to aluminum. This is due to the fact that the insert spreads the load out over a greater surface than the bolt by itself. This approach to applying fasteners should provide a reliable, strong interface for components to parts manufactured on the BAAM system.

Impacts

The ORNL BAAM system has tremendous potential in terms of manufacturing. The present application area is focused on tooling. However, many of the fundamental questions addressed in this project expand the capabilities of the system well beyond making simple structures. Having the ability to manufacture overhanging structures as well as defining reliable methods of attaching BAAM manufactured parts to other components expands the potential application area. This project is focusing on the enabling technologies required for rapidly manufacturing custom electric vehicles. However, success goes well beyond automotive applications. Other applications that are of interest are wind turbine blades. Is it possible to manufacture complex structures for the wind turbine industry at large scale and low cost? More advanced tooling applications require the ability to integrate cooling passages into the structure or integrate actuation for rapid part removal. The major contribution of this project is the demonstration of a path towards large scale manufacturing of systems as well as parts.

Conclusions

The primary metric for success for this project was the ability to manufacture a complex structure indicative of what will be developed for Local Motors vehicles. Two specific issues that needed solutions were 1) how to handle overhanging structures and 2) how to securely attach other components to the printed structure. The team successfully demonstrated that structures could be manufactured reliably with overhangs under 45 degrees and that break away supports were perfectly suitable for manufacturing overhangs that exceeded this limit. The team also quantified the pull out force associated with threaded inserts and measured the yield stress between 37.0 ksi and 43.7 ksi, comparable to aluminum. This approach to embedding mechanical attachment points is reliable, low-cost and rugged.

The next phase of the project is to manufacture a full scale car body. The system will require advancements in the area of lattice in-fills for weight reduction, actively embedding structures within the build process (motors, sensors, wiring harnesses…). The overall objective would be to manufacture a full scale system by the end of the project. If successful, it will not only demonstrate the feasibility of true additive manufactured vehicles but will also demonstrate the path forward for additively manufactured systems.

About the Company

Local Motors (LM) started in 2007 to create a community-based co-creation facility both on-line and physically whereby members could freely collaborate and challenge each other to vet ideas and develop the most desired products as quickly as possible. Local Motors then tied this co-creative community and its ideas to a network of Micro-Factory + Lab spaces whereby it develops these ideas along with the participation of the community members. Development includes rapid product design and iteration in addition to small volume manufacturing.

Points of Contact

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