Additive Manufacturing (AM) and the Honeywell Global Initiative

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Abstract

This paper documents the status of metal Additive Manufacturing (AM) within Honeywell and the company's global initiative to incorporate the technology across four business sites. Four Additive Manufacturing Technology Centers (Phoenix, Bangalore, Brno, and Shanghai) were established within the past few years to accelerate Honeywell's entry into this rapidly growing manufacturing sector. The global labs are focused on producing prototypes, tooling, and conducting material and process characterization. As the technology moves closer to production, Honeywell's AM labs are helping to grow the collective process and design knowledge critical to ensuring high quality production components made from additive manufacturing.

Introduction

The field of additive manufacturing compromises several different variations and processes focusing on either polymers or metal materials. Within Honeywell, the Global AM labs are focusing on a specific type of additive called powder bed fusion (PBF) for metal materials. In this process, fine powders of the material are spread in thin layers while an energy source (i.e. laser or electron beam) is used to fuse the pattern onto the powder bed.

This technology is experiencing rapid growth in both aerospace and medical manufacturing industries due to its unique ability to make repeatable, accurate, and complex geometric components at a cost advantage when compared to traditional manufacturing methods. As a result, several benefits such as increased efficiency, reduced weight, lower cost, and faster delivery can be realized by companies employing this technology within their core manufacturing base.

Honeywell has recognized the need to keep pace and has established powder bed additive laboratories in four global sites. Phoenix, Bangalore, Brno, and Shanghai were selected as the sites for these labs due to their proximity to Honeywell's global manufacturing and engineering base. A set of 5 initiatives were established for the Global AM labs in order to align Honeywell's AM mission, establish the path forward to production, and grow the design knowledge necessary to take advantage of the process benefits.

Goals for the Four Global Technology Centers:

There are five primary goals with the AM Initiative, which are: 1) Development of prototypes and lead time reduction, 2) Reduction of tooling costs, 3) Material and process development, 4) Development and implementation of the global supply base, and 5) Working with Honeywell locations on Design for Additive learning and experience.

Prototypes and Lead Time Reduction

Each of the four facilities is chartered to work with Enterprise and Advanced Technology Engineering functions to produce prototypes for testing and evaluation. Additive Manufacturing makes prototypes very fast and at a fraction of the cost of conventional methods. This enables engineering teams to fabricate several parts with slight variations in their geometries to quickly determine the best design. With AM, project teams are able to reduce lead times for prototype parts by up to 70%.

This was first displayed in a project involving the Tangential On-Board Injector (TOBI) for the HTF7500E (HTF7000-2) Program. The TOBI shown in Figure 1 was initially cast using a core-die/wax-die casting approach. However, air flow for the final machined part was approximately 5 percent above engineering design intent. A new part was needed, but the engine program required a series of engine tests be conducted within weeks. Since a new core/wax die for the TOBI would take months, the team implemented AM Technology and was able to produce three parts in 8 weeks. Ten months later, after the engines were tested at Honeywell's research test facility and after a test engine was even mounted on the Honeywell Boeing 757 Flight Test Bed, a new cast TOBI was finally delivered to Honeywell by the casting vendor. Additive Manufacturing enabled critical cycle time reduction to support a key certification program.

Figure 1: TOBI Ring for HTF7000

AM Technology was also used to produce turbine blades for a Phoenix test rig for a Helicopter program. Figure 2 shows a picture of a High Pressure Turbine Blade produced using AM Technology. It normally takes 18 months to make a core/wax die set of tooling, and some of this tooling can cost upwards of $500K - $800K. The Turbines Group used AM Technology to produce four sets of turbine blades in 9 weeks. After each build, the blades were inspected via Structured Light Inspection techniques (white light) and each was tested with air flow measurement devices. After each build, the CAD files were changed slightly and a new AM build took place. Within four builds (a duration of 9 weeks), the final blade design was documented. This process of measuring and flowing blades using conventional casting technologies would have taken 3 years or more to accomplish. With additive manufacturing, this time was reduced to 9 weeks- and without tooling costs. Once the final blade geometry was completed, the Engineering Team was able to work with the casting vendor to make the desired single crystal cast blade without multiple casting iterations. This technology has also been used to build High Pressure Turbine Nozzles shown in Figure 3.

Figure 2: 2nd Stage HPT Blade for HTF7000

Figure 3: 2nd Stage HPT Nozzle for HTF7000

A recent example of prototyping within the Global AM Labs is an atomizer shroud for the new 131-9 APU variant HGT750 shown in Figure 4. The design team was tasked with developing a shroud design that minimized combustion gas emissions. In initial testing, the team found their design had issues with carbon build-up on the atomizer nozzle tip. To mitigate this carbon build-up, several design changes were made via additive manufacturing in the Phoenix lab. Where a typical design iteration would take several months to manufacture conventionally, AM helped the team receive components for testing in a matter of weeks.

Figure 4: Atomizer shroud for 131-9/HGT750.

Reduction of Tooling Costs

Each of the Honeywell locations spends considerable amounts of money for tooling. It has been shown, the return-on-investment associated with Additive technology can be maximized through the use of producing AM tooling. A perfect example is that of an inlet booster rake for measuring airflow turbine engine test cells. A previous order of 10 sets of these rakes cost $50,000 due to the vendor requiring a combination of welding, brazing, EDM machining, and other conventional methods to make the complex shapes.

The Phoenix Additive Manufacturing Technology Center (AMTC) was provided the same design and produced a set of 10 rakes for under $7,000 total cost including post-processing. Figure 5 shows the additively build inlet booster rake and a cross-section of the inside channels which emphasizes the complexity of the design.

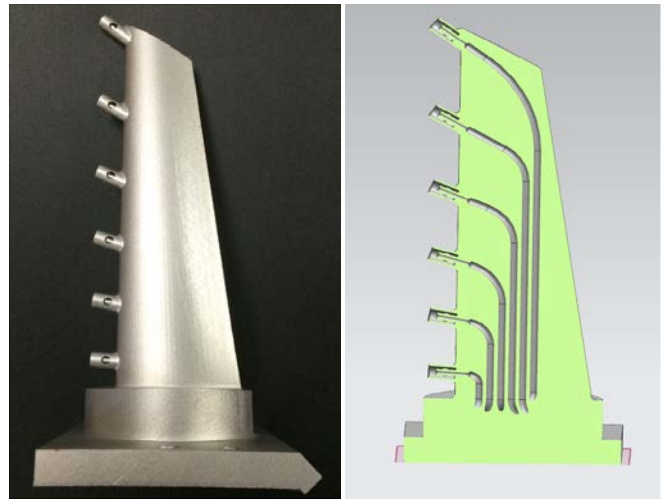

Figure 5: AM-built Inlet Booster Rake and cross-section.

Materials and Process Development

At the 2013 Honeywell Technology Symposium, representatives from all Honeywell business groups met to determine and prioritize which materials should be characterized based on benefit and future growth.

It was not unexpected that a large number of materials were requested. Nickel and Cobalt-based superalloys were high on the list, as were aluminum and titanium alloys. As a starting point, several common alloys were selected, test bars were fabricated via powder bed fusion process at multiple vendors, and baseline mechanical property data was collected.

The most advanced data was collected for IN718 nickel-based superalloy. The results for IN718 as well as several of the materials tested showed that AM-built specimens exhibited superior tensile and LCF/HCF properties when compared to cast material. Figure 6 shows a graph of IN718 as-built bars compared to cast IN718.

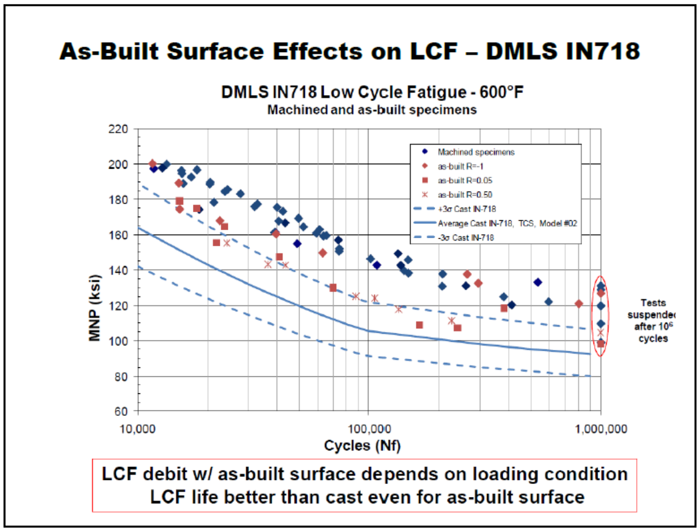

Figure 6: Surface Effects on LCF for DMLS 718

In some cases, AM-built mechanical properties approached and even exceeded those of wrought materials. However, given the infancy of this technology, powder bed fusion AM is viewed as a possible replacement or equivalent for cast materials and not yet considered an equivalent replacement for wrought material at this time.

Material development within the Global AM Labs is moving quickly under the guidance and oversight of the Materials and Process Engineering Group in Phoenix. This work involves characterizing several aspects of the process, including powder, machine, equipment, parameters used as well as testing AM-built material made under fixed process conditions.

Specifications have been written for powder used in PBF machines, and a process specification for PBF is currently in review. Fixed process creation and quality control procedures are being developed with the goal of production by the end of 2015. Powder re-use studies are also being conducted by the Global Labs to understand how to recycle powder for maximum cost savings.

In-process monitoring is another area that the Global AM Labs have been growing internal knowledge and building databases for quality control purposes. Melt pool monitoring, real-time feedback of the laser, and dimensional monitoring of parts and powder are key areas of focus. Through a combination of internal projects and government funded DARPA investigations, Honeywell is building the core knowledge base required to utilize in-process monitoring for AM.

Still, a key area that needs further development is that of post-processing and inspection of AM parts. Effective methods of surface finishing and non-destructive evaluation must be addressed for the process to gain production acceptance. The Global AM Labs have initiated efforts into these areas but more must be done.

Development of the Global Supply Base

Just as Honeywell is beginning to implement AM technology, the supply base poses a risk if not properly managed. Experience to-date has shown that the North American supply base is very immature and not yet ready to meet the stringent requirements of aerospace production.

Honeywell locations using these services must consider that these types of companies offer printing services only. They will not provide a guarantee that the AM processed material will meet engineering design intent. For the near term, these companies provide a valuable service by producing components for prototypes. These companies often want to bid on printing production parts. The manufacturing of production parts using additive manufacturing technology must be managed via a fixed process and by a vendor that is approved by Honeywell Quality and the Materials and Process Engineering organization.

Honeywell is moving this technology into being a qualified process using either in-house capability or with a vendor that has stringent quality control processes audited and approved by Honeywell.

Design for Additive Manufacturing

Understanding the new design freedoms that AM Technology provides will require cultural change. Design engineers must learn the advantages this new manufacturing method provides with regard to component design opportunity.

Honeywell is working with corporations and universities to train Honeywell designers to better understand the technology and the design freedoms 3D printing makes available. Just recently, an introductory class on AM Design and Process was given to over 50 Honeywell Design Engineers at the Phoenix Learning Center. The Global AM labs are also working with multiple project groups on evaluating designs for AM. Various exercises such as incorporating manufacturing build rules and geometric optimizations are currently carried out on a daily basis.

For wide scale implementation, it is envisioned that software tools will assist the designer in understanding how to shape components in the most efficient way for AM. This growing field is termed Topology Optimization. The AM Global labs are working with teams in Advanced Technology and Design Engineering to evaluate multiple 3rd party Topology Optimization software platforms.

As an initial exercise in re-design of components for AM, a case study was made on the TPE331 engine mount bracket. Figures 7 and 8 show the redesigned part, which resulted in a 50% weight reduction while maintaining design intent. The Phoenix AMTC then built the re-designed part to demonstrate design to manufacture feasibility.

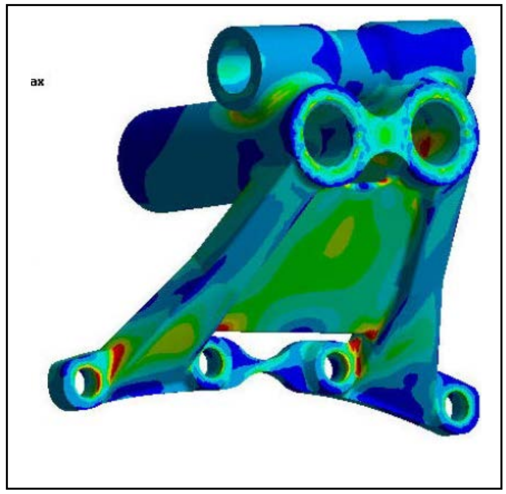

Figure 7: ANYS analysis of re-designed TPE331 Engine Mount confirming design loads sufficient. Weight reduction of 56% from current design.

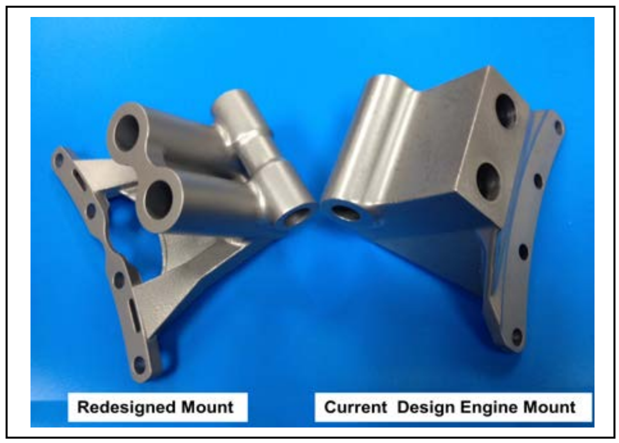

Figure 8: Photo of AM-built TPE331 Engine Mount next to current design TPE331 Engine Mount.

The Future

Over the next several years, the Global AM Labs will continue to increase Honeywell's knowledge and expertise in powder bed additive manufacturing. Expansions of the labs are currently being undertaken in Phoenix, Brno and Shanghai. The addition of reactive metals capability such as Al and Ti alloys will be a reality in 2016. A large scale machine capable of printing parts twice the current build volume size will be implemented in both Phoenix and Brno in 2016. Bangalore will be expanding their laser machine capabilities as well as their test lab support. Shanghai has installed a new laser machine with more planned in 2016.

In addition to metals, the Global AM Labs will initiate growth into polymer and ceramic materials. Increased focus on tooling will drive the need for polymer capability. For ceramics, extreme temperature environments are driving the need to explore ceramic materials for traditionally metal components.

Within Honeywell, production of AM-built components is expected to grow significantly as design knowledge increases and AM-centric designs become more common. Topology Optimization is expected to be a core competency within Honeywell Design and software tools available to all design engineers.

The technology itself will continue to grow, with larger machines, more automation, better as-built surface finishes, and more refined process monitoring systems to ensure part quality. Investment must keep pace if Honeywell is to remain a key player in this manufacturing sector.

Summary

Each of the four Additive Manufacturing Technology Centers have the same goals which include the production of prototypes as well as tooling for their respective organizations. The drive to characterize and develop the process is a key part of implementing this technology into production at Honeywell. The ability to integrate our process expertise with Design for Additive will be fundamental to Honeywell's future use of powder bed fusion technology.

The journey has begun and Honeywell will continue to move quickly to develop, validate, and safely integrate this exciting new technology into our core businesses and products.

Innovation and brilliant minds will control the future of Additive Manufacturing. By unleashing the minds and imaginations of the Honeywell Organization its customers and stock holders will benefit with each new application of this technology.

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