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Industrialising AM - creating predictable, productive processes

The recent emergence of the term Additive Manufacturing (AM) bears witness to an ongoing transformation in the use of additive technologies, away from low volume 3D printing and towards series manufacturing. This feature article explores the drivers behind this trend to industrial AM, and the technical developments that will be critical success factors in this transition.

What do we mean by industrial AM? Firstly, we are talking about a factory floor process rather than one that is used in the research lab or tool room, in which the focus is on making parts for series production rather than prototypes or tooling. Here, our goal is to use the unique capabilities of AM to maximise product performance, rather than merely to compress manufacturing lead times.

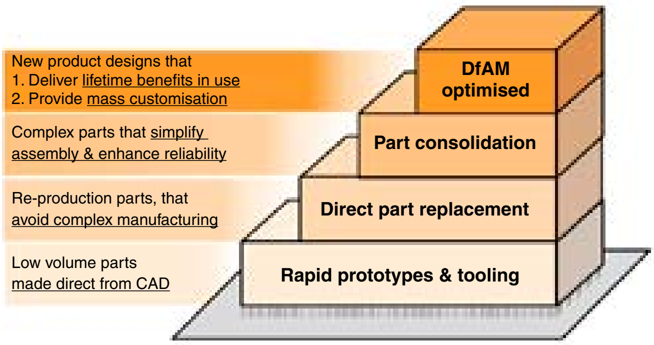
The outputs of an industrial AM process are consistent, qualified parts that exhibit high integrity and that are suited to a long service life, rather than shapes for modelling or evaluation. Materials are chosen for their strength and integrity rather than their cosmetic appearance or ease of processing.

And finally, we need to consider far more than just the 3D printing aspect of an industrial AM process, extending our thinking to include the entire process chain that is necessary to design, build, finish and verify the AM products:

- from research lab on to the factory floor
- from prototypes and tooling to series production
- from time compression to higher product performance
- from shapes to consistent, qualified parts
- from plastics to high performance alloys
- from 3D printing to an integrated production process

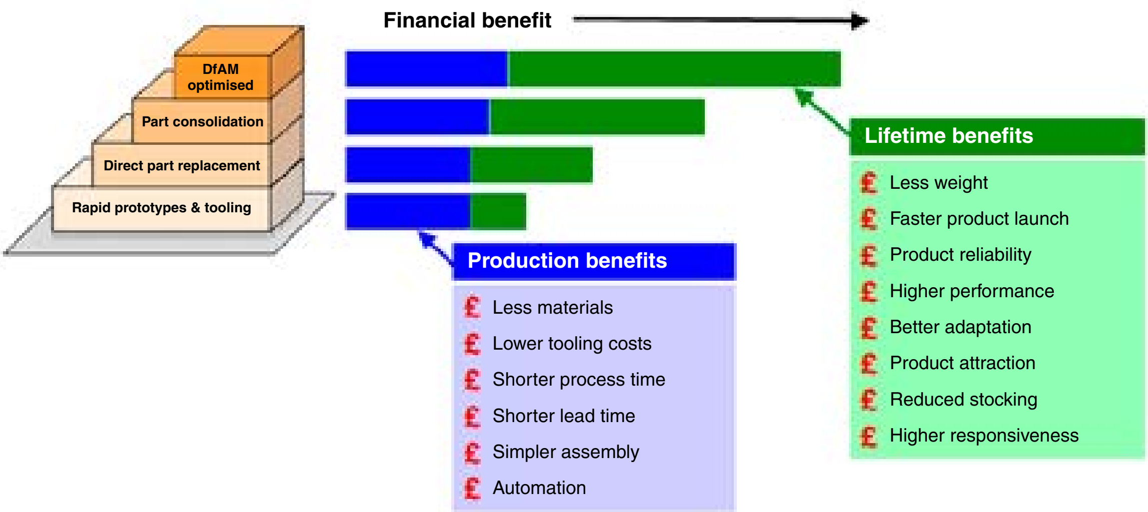
Drivers for industrialisation

In previous articles we introduced a staircase model of AM deployment which shows the progression that many firms go through in their use of AM. The higher staircase levels involve more sophisticated design for AM (DfAM) practices.



As you climb the staircase, you use more and more capabilities of AM to create increasingly valuable products. The lower steps are primarily about production benefits such as time compression, tooling elimination and minimal material waste. As you move up through part consolidation and into DfAM optimised parts, your focus increasingly shifts to the impact that AM can have on product performance and the lifetime benefits that accrue as a result.

For more information about the capabilities of AM and their impact on product design, refer to the feature articles Additive impact part #1 and Additive impact part #2.



So, the value of industrial AM lies more in the product than in the production process. It is these product performance benefits that will ultimately drive the industrialisation of AM. By creating products that perform in new and better ways, or by using AM to deploy new business models that provide a superior service to customers, we will create the value that will justify investment in AM processes and factories.

This industrialisation will apply in many fields, and not just in early-adopter sectors such as aerospace and medical devices. Look out for lightweight, efficient, attractive and customised AM products in many other markets, including consumer products.

Integrated manufacturing process chains

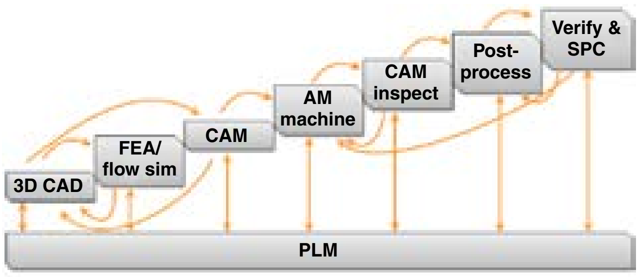
As stated earlier, for an industrial AM process we must consider more than just the additive process step. To be useful, every manufacturing process needs an effective chain of tools that work together to design, prepare, produce, control and verify the output.

AM is not an island: producing near-net shape parts is nowhere near enough when you're looking in a production context. Anyone who promises that AM can make you anything you want is not telling the whole truth - few parts on exhibition booths are in the raw state that they emerged from the AM machine.

The advertising promise

The reality

So, AM must be underpinned by an effective process chain with user-friendly design tools and a range of post-processing and metrology activities before the parts it makes can be used in anger. Information must flow up and down the chain to link processes together, with control loops being used to minimise process variation:



Process chains of this type are now emerging, although the tools involved are not yet integrated and mature. A good example of this is the work that Renishaw have done with Land Rover Ben Ainslie Racing to develop a manifold component for the £80m America's Cup sailboat. The feature article Race to innovate explains how the manifold is designed, as well as the chain of processes that are necessary to build, gauge, finish and inspect it.

Future process chains

The ideal process chain for industrial AM will start with CAD tools that are optimised for AM part design - currently an area of high focus for the CAD sector. Parts will be designed for AM from the ground up, rather than undergoing an adaptation process from a conventional design as something of an afterthought.

We also need close links between CAD and the world of AM build file preparation and post-process development. Our process development thinking must include optimisation across all the steps in the process chain, so that we don't minimise costs in the build only to see them rise again in complex or manual finishing processes.

As it is in all manufacturing processes, metrology is the 'golden thread' through this process, transferring datums, providing feedback and verifying conformance. At each link in the chain, process controls act to minimise variation and deliver predictable outcomes:

- CAD tools optimised for AM part design
- Integrated build file preparation and post-process development
- Metrology as a 'golden thread' through the process
- Process controls to minimise variation at each link in the chain

Productive AM processes

Successful industrial processes are productive and predictable. Variation is the enemy of productivity and it can be squeezed out through rigorous control of the environment, inputs, set-up and operation of each process step.

We are used to taking this approach with conventional manufacturing processes such as machining. This rigour underpins the automated factories that produce everything from the sleek phone in your pocket, to the fuel-efficient car you drive and the reliable aircraft that you fly in.

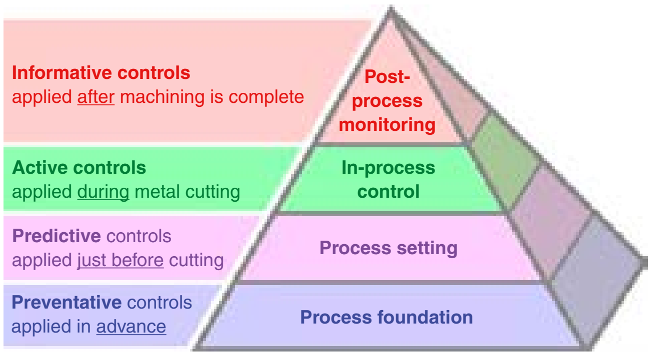
Renishaw uses a framework that it calls the Productive Process Pyramid™ to identify and control manufacturing process variation. Well-proven in the metal cutting arena, it applies equally to industrial AM. It comprises four layers:

Process foundation
Preventative controls applied in advance to ensure that process inputs and the operating environment are consistent

Process setting
Predictive controls applied just before processing to ensure that the machine is ready to make good parts

In-process control
Active controls applied during the process itself to monitor and respond to drift and unexpected errors

Post-process verification
Informative controls applied after manufacturing is complete to verify the integrity of the output



So how does this apply to AM? Firstly it is important to note that AM is relatively immature compared to conventional manufacturing methods and so some of the necessary controls are still emerging. This is an area of intense focus for system builders and leading AM users, so expect developments in the following areas:

Process foundation

The foundation is all about making sure that the operating environment is optimised and stable. Foundation controls include methods to calibrate the AM machine's optical and motion systems and quick, periodic health checks of the laser system performance. A consistent approach to developing the build process, using proven laser parameters and build strategies, is also critical. And control of process inputs such as powder condition through sampling and test piece analysis, builds confidence that we are in a position to make good parts.

Process setting

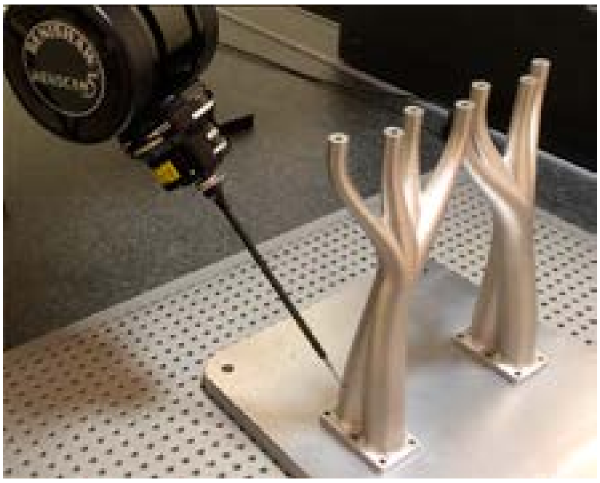
These are the checks and controls that we run just before the laser first fires. Setting controls include ensuring that we have the correct build file loaded, and that we have loaded our machine with the correct amount of powder. We need to check the condition of critical systems like the exhaust filters, and also the position and alignment of our dosing 'wiper'. And, of course, we must ensure that we have removed oxygen from the build chamber and that the operating temperature is correct.

In-process control

Now we are up and running and the focus moves to control of the build process itself. We need to be confident that each layer doses correctly, and that the previous layer is covered with fresh powder. We may also monitor the temperature and size of the weld pool to be confident that we are processing powder consistently, and we can look to see that we have achieved the correct overlap of weld tracks on critical component surfaces. Filtration of the gas flow and sieving of powder to remove under- and over-size particles and maintain powder quality are critical. We also want to monitor the chamber temperature and oxygen levels throughout to ensure consistent processing conditions.

Post-process monitoring

Now that our build is complete, we need to verify that our parts conform to specification. Controls here will include inspection of the part dimensions and surface finish on a co-ordinate measuring machine or a gauging system, using a combination of contact and camera-based sensors. Internal inspection of the part using X-rays and ultrasonics can add vital detail, and a regime of test piece destructive testing will also be necessary in some applications.



REVO 5-axis inspection system measuring a topologically optimised AM component

Summary

Additive manufacturing's development from a prototyping technology into a mainstream production process will be driven by applications that make use of AM's capability to produce high-performing products that cannot be made any other way.

Capable production processes will be supported by chains of tools that span the entire production process from design to verification, not just the AM process step.

And industrial AM processes will be underpinned by layers of control that minimise variation and certify AM production quality.

With all this in place, AM can take its rightful place in the family of advanced manufacturing technologies used for series production.

About the author

Marc Saunders, Director of AM Applications

Marc Saunders has over 25 years' experience in high tech manufacturing. In previous positions at Renishaw, he played a key role in developing the company award-winning RAMTIC automated machining platform, and has also delivered turnkey metrology solutions to customers in the aerospace sector.

Marc manages Renishaw's global network of Additive Manufacturing Solutions Centres, enabling customers who are considering deploying AM as a production process to gain hands-on experience with the technology before committing to a new facility.

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