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CASE STUDY

Accelerating AM process parameter optimisation with machine learning

A project with the AMRC, Constellium, GE Additive, and Boeing

Executive summary

Machine learning can make the additive manufacturing (AM) process for metallic alloys in aerospace cheaper and faster, supporting the production of lightweight, fuel-efficient aircraft. In collaboration with the University of Sheffield Advanced Manufacturing Research Centre **(AMRC)** and **Boeing**, **Intellegens** applied the Alchemite™ machine learning software to design new AM parameter sets for laser powder bed fusion (LPBF) and test them for nickel base alloys across two experimental cycles. Results from the second cycle showed good agreement with the predictions. The model was then used to develop process parameters for the new additive-specific Aheadd® CP1 powder from **Constellium** in combination with the 400W M2 machine from **GE Additive**. The project team was able to move from the new powder to final parameters in just two builds, while applying no expert statistical knowledge. This shows how Alchemite™ machine learning can dramatically speed up AM process parameter optimisation.

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Challenge

Additive Manufacturing (AM) is a rapidly-evolving manufacturing technology that delivers lighter, stronger components with great flexibility in part geometry and the potential for on-demand manufacturing. Its benefits are recognised in many sectors – notably in aerospace, where it can support lightweighting of aircraft, increasing fuel efficiency.

But there are **significant practical challenges** in implementing AM. New component specifications often require a new metallic powder material or a new AM machine. Finding the right machine processing parameters is tricky, since final properties are notoriously sensitive to small variations in material, machine setup, or environmental conditions.

Optimising AM parameters usually proceeds via time-consuming, costly experimentation

Optimising these parameters usually proceeds via time-consuming, costly experimentation. Parameter space is narrowed down using **experimental design methods** plus the knowledge of AM project teams. Knowledge is often lost between projects as changes are made in machines, powders, and team members. Conventional experimental design, even using sophisticated statistical analysis, rarely reduces the number of tests sufficiently, leaving a heavy experimental burden.

Machine learning (ML) should help in two ways. ML methods learn from historical data, capturing knowledge in re-usable models so that experience from one project can be applied elsewhere. And these models, which describe subtle relationships in complex, high dimensional data, can be used predictively, reducing the need for experiments. But ML methods have constraints. They learn from 'training data'. Conventional ML requires this data to be complete for all parameters of interest. But real-world experimental data, often assembled from multiple tests, targeting different properties, and where project teams may be unsure which parameters to measure, are **sparse and noisy** – they contain gaps.

Is it possible to apply ML to accelerate AM parameter optimisation?

Solution

Project MEDAL addressed this challenge. This collaboration, supported by the UK National Aerospace Technology Exploitation Program (NATEP), involved **Intellegens**, the University of Sheffield Advanced Manufacturing Research Centre (**AMRC**), **Boeing**, **GE Additive**, and **Constellium**. The heart of the project was the **Alchemite™** machine learning technology [1], originating at the University of Cambridge and further developed at Intellegens. Alchemite™

tackles difficult material and process design problems. A core property is its ability to handle sparse, noisy experimental data. It ingests historic project data, builds an ML model, and can use that model to predict or optimise outputs of new systems.

In **Phase 1** [2], Intellegens, the AMRC, and Boeing built an ML tool for AM based on Alchemite™. The focus was laser powder bed fusion (LPBF) and the project constituted a major study into process parameter development. Every time a new input to the system (e.g., a new material, machine, part, or even operator) was available the model, based on historical data, could be used in real time to guide the choice of process parameters for the next experiment. In this way, parameter space was explored with maximum efficiency. *Figure 1* shows how Alchemite™ (blue line) can optimise a given target based on far fewer experiments (in many cases 10x fewer) than conventional experimental design methods.

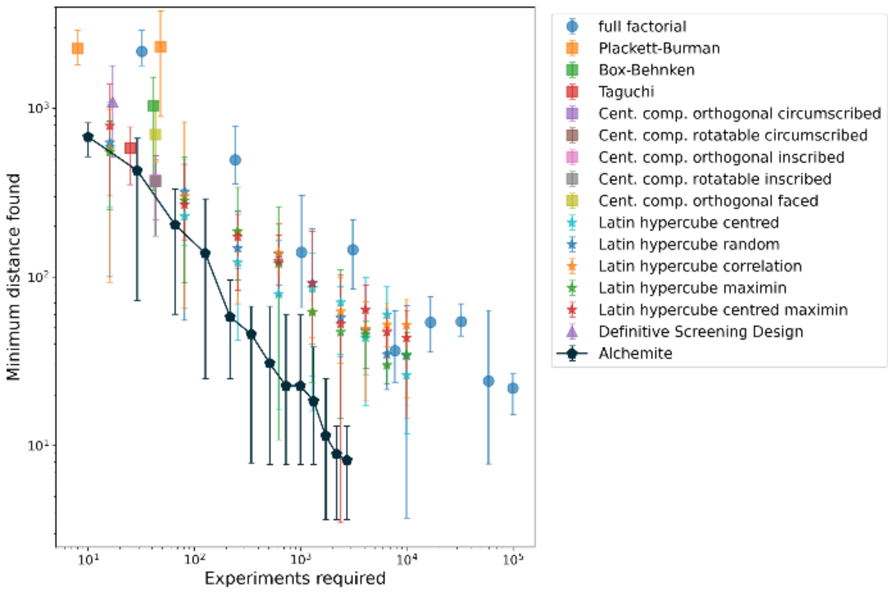


Figure 1. Comparing Alchemite™ with standard experimental design methods.

In **Phase 2** of the project, this ML tool was applied to a new AM-focused aluminium powder from Constellium, Aheadd® CP1. The tool was used to optimise process parameters as test samples were built in GE Additive's 400W M2 machine and subsequently tested, with a focus on optimising Ultimate Tensile Strength (UTS).

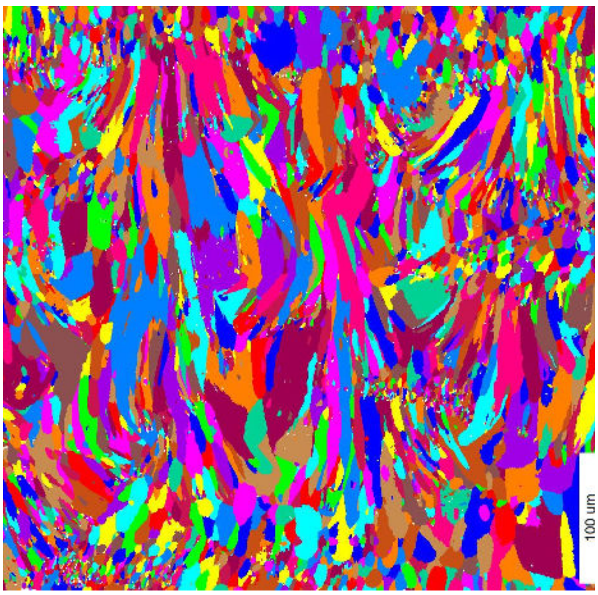


Figure 2. Grain structure of a sample printed using Constellium Aheadd® CP1 >

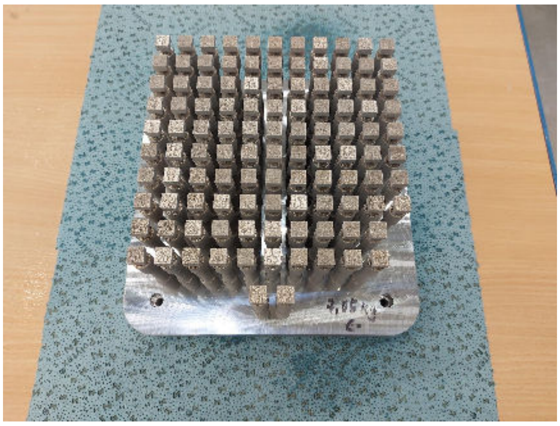
Outcomes

Phase 1 demonstrated that it was possible to learn from historic builds and apply the resulting model to new builds. The outcomes from a first experimental cycle were used to predict the results of a second cycle, with close agreement between the predicted and experimental results.

Alchemite™ enabled rapid identification of the optimal process parameters for the new powder and machine

In Phase 2, working with the Constellium powder and GE Additive machine:

- The AMRC engineers could apply the Alchemite™ machine learning tool to guide their work with no expert knowledge of the powder.
- The machine learning approach was found to be applicable to multiple different powders, machines and AM processing types.
- After just one build the Alchemite™ machine learning tool was able to accurately predict the UTS performance of parts in the second build (Figure 3).
- The Aheadd® CP1 powder provided stable, predictable performance except for where insufficient laser power led to lack of fusion.



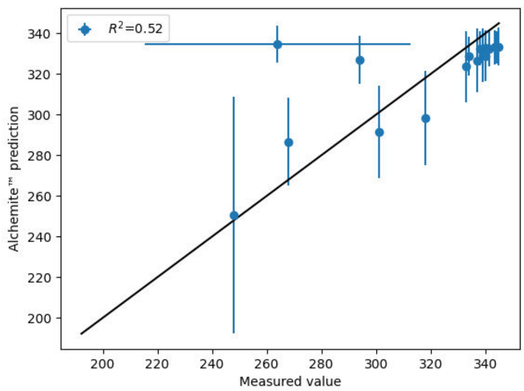


Figure 3. Test samples built during Phase 2 of the project (left) and a comparison of Alchemite™ predictions for the second build UTS with experimentally measured values, showing high agreement (right).

Conclusions

The project demonstrated the effectiveness of Alchemite™ machine learning in accelerating process parameter optimisation for a new AM process. Such a capability will enable AM process teams to bring new processes to market faster, by significantly reducing the amount of experiment involved.

AM teams can bring new processes to market faster and understand key process / property relationships

Ian Brooks, who was then a **Technical Fellow at AMRC North West**, led the project. He commented: "Alchemite™ converged on the optimum solution with far fewer experiments. The opportunity for this project is to provide end-users with a validated, economically viable method of developing their own powder and parameter combinations."

The predictions made by the ML model can also be analysed using a suite of graphical analysis tools in the Alchemite™ Analytics platform, for example, to find out which input parameters drive key outputs. Such understanding of process / property relationships enables AM teams to get the most from material and machine innovations as they pursue reliable, repeatable AM processes.

Quoted in *Metal Additive Manufacturing* [3], **Lukas Jiranek of Boeing Research & Technology** explained the company's involvement: "There are currently over 70,000 AM components flying on Boeing platforms. With these multiple efforts and the data-rich AM process chain, machine learning has the potential to be a key technology in accelerating the further development and adoption of AM. Project MEDAL is a valuable step in creating and proving-out standardised approaches to machine learning for data-driven AM process parameter development."

"Machine learning has the potential to be a key technology in accelerating further development and adoption of AM"
Lukas Jiranek - Boeing

Ravi Shahani, Additive Manufacturing Strategic Partnership Manager at Constellium, adds: "There is huge potential for alloys designed specifically for laser powder bed fusion. This project has confirmed the robust performance of Aheadd® CP1 on the GE Additive platform, and the approach demonstrates we can reach predictable mechanical performance very quickly. Machine learning will allow us to reach optimised AM solutions faster in multiple application areas for Aheadd® CP1, including heat exchange, satellite components, high-end automotive parts and semiconductor industry equipment"

Find out more about data-driven additive manufacturing at **intellegens.com.**

About the project participants

Intellegens provides unique machine learning software, Alchemite™. We make it easy to apply machine learning to accelerate innovation in materials, chemicals, manufacturing, and beyond.

The University of Sheffield Advanced Manufacturing Research Centre (AMRC) is a network of world-leading research and innovation centres working with companies involved in manufacturing of all sizes from around the globe.

GE Additive – part of GE – is a world leader in metal additive design and manufacturing, a pioneering process that has the power and potential to transform businesses.

Constellium is a global leader in the development and manufacturing of high value-added aluminium products and solutions. Its advanced alloys and engineered solutions support a range of applications, such as cars, beverage cans, airplanes and more.

Boeing is the world's largest aerospace company and leading manufacturer of commercial jetliners, defense, space and security systems, and service provider of aftermarket support.

References

1. "Alchemite™ deep learning - solving complex problems with real-world data", Intellegens white paper (2021)

2. Press Release: "Machine learning making light work of additive manufacturing aerospace alloys", The University of Sheffield Additive Manufacturing Centre, Jan 2021.

3. Warde S., "The inestimable value of AI: How Machine Learning can help AM project teams achieve their goals and beyond", *Metal Additive Manufacturing* Vol 7 No. 4 (2021)

Graphics credits. Figure 2 courtesy of Constellium.

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