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CASE STUDY

Tooling optimisation for composite drilling using deep learning

The University Of Sheffield. / AMRC Advanced Manufacturing Research Centre

Executive summary

Laminated fibre-reinforced polymer matrix composites are widespread in aerospace and increasingly used in other sectors, such as automotive. Identifying optimal cutting parameters for a given tool-composite pair is of utmost importance, since this can considerably reduce component non-conformance. Surface delamination during machining results in 60% of part rejections during final aircraft assembly. Understanding and controlling delamination requires significant experimental effort, typically involving systematic drilling and analysis of a thousand holes. The Intellegens deep learning software, Alchemite™, can reduce this experimental time by quantifying complicated nonlinear tool-composite relationships. It enables analysis, understanding, and sharing of complex data relationships, guiding tooling design and selection prior to experimental campaigns. In a study at the University of Sheffield Advanced Manufacturing Research Centre (**AMRC**), Alchemite™ delivered useful predictions of future tooling performance from sparse and noisy data based on 80% fewer experiments and identified irrelevant features for predicting tool performance, facilitating further experimental cost savings.

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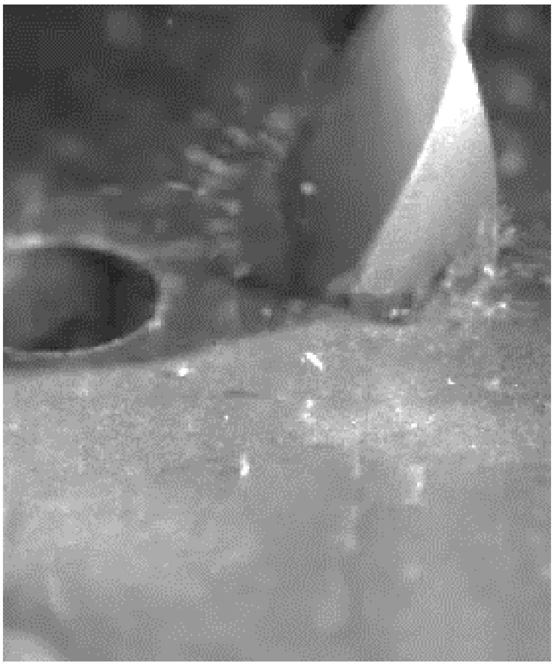
Challenge



Laminated fibre-reinforced polymer (FRP) matrix composites are increasingly common in industries with a drive towards high-performance lightweight components, such as aerospace. This is due to their excellent mechanical properties and highly-tailorable design. Although such tailorability increases design options, it can negatively impact costs, productivity, and sustainability during manufacture. This is particularly apparent in machining, where FRP part-specific defects occur.

Process uncertainties resulting in large, unpredictable defect generation are a common cause for prescribing overly-conservative cutting tool use limits, based on part quality criteria. Due to the wide array of tool designs and workpiece material configurations available, an application-specific approach is required to identify the most effective cutting strategies. Optimal cutting parameters can be found using an exhaustive, wide-boundary, DoE-based approach, with slow and costly testing required to identify absolute tool life limits.

Analysis was particularly challenging since 82% of the target data was missing

The work described here establishes a novel machine learning-based method to predict tool life from start-of-life performance data, reducing experimental time and cost. The project was particularly challenging, because the original dataset was sparse, with 82% of the target data missing.

Solution

Alchemite™ [1] is Intellegens' novel machine learning software, which leverages the unique insights of deep learning to build comprehensive models from sparse and noisy data. In this study, tooling time series data on 55 drill/composite pairs, recording 23 machining responses, including hole quality metrics and in-process measurements, was provided by the

AMRC. This data was easily uploaded into the Alchemite™ Analytics software using its intuitive drag-and-drop interface.

Data from just 200 tests was sufficient to provide deep insight into future performance

A deep learning model was trained on the tooling dataset. Despite the missing 82% of data, Alchemite™ was able to train a model with a high coefficient of determination of 0.73. This high accuracy was accomplished using the core Alchemite™ algorithm in combination with a variety of data pre-processing steps to reduce the inherent noise. These steps included data grouping and then aggregation (Figure 1). Although data from over 1,000 holes was available (a typical testing dataset), analysis showed that, with the right aggregation, 200 data points were sufficient to provide deep insight into a tool's future cutting performance.

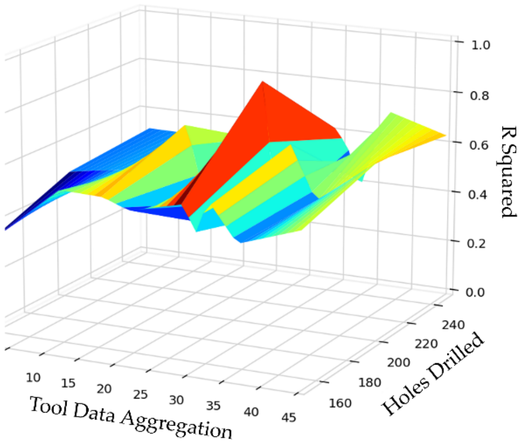


Figure 1. Alchemite™ identifies the optimal holes drilled for predicting future tool performance. The plot shows how the accuracy of the model (R-squared) can be improved by optimising data aggregation and that data from 200 tests ('holes drilled') enables high accuracy.

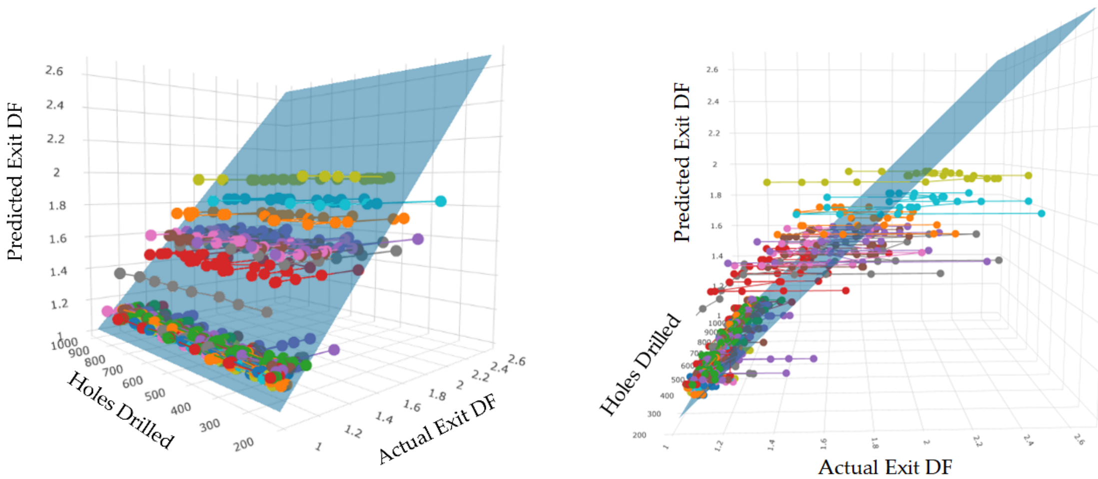


Figure 2. Two projections of a 3D plot showing how the accuracy of predicting exit delamination factor (DF) varies with the number of holes drilled. Each colour in the connected points indicates a unique tool-composite pair

Outcome

By gaining insight from sparse data to quantify underlying, complex nonlinear property/property relationships, Alchemite™ created a tool-composite model with good predictive power. The ability to accurately predict exit delamination (Figure 2) for some future number of drilled holes enables tool life to be estimated, and the impact of factors such as tooling geometry and material selection on this tool life to be studied. This can inform the design stage of an experimental campaign, ensuring that unsuitable tools are not unnecessarily tested and that only the most promising candidates are taken forward for more comprehensive tooling trials. Making useful decisions based on only 20% of the typically-acquired performance data allows progress based on far fewer tests, resulting in up to 80% reductions in the direct costs associated with testing, such as material wastage, machining and technician time, as well those associated with equipment maintenance and overhaul. The use of explainable AI tools in Alchemite™, such as the importance chart, enabled identification of variables that were irrelevant to predicting tool life performance, allowing additional experimental streamlining.

Alchemite™ could enable an 80% reduction in the direct costs associated with testing

Future opportunities

The predictive accuracy of Alchemite™ increases in proportion to the amount of data added. Therefore, as the tool-composite database increases, the optimum tool for a new composite component can be determined with increased certainty. Consequently, this project could be extended to identify optimal tool-composite pairs with a more guided approach, reducing experimental time and cost. More importantly, populating the tool-composite database with new experimental data will lead to a deeper understanding of the high-dimensionality feature space, resulting in a continual cycle of improved operational performance.

About the AMRC and Intellegens

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. The AMRC has undertaken a number of historic CFRP and CFRP/metallic stack drilling trials in order to help industry develop economic methods of controlling drilling-induced delamination.

Intellegens provides a unique machine learning solution for real-world experimental and process data problems in industrial R&D and manufacturing. The Alchemite™ deep learning software, based on a methodology that originated in the University of Cambridge, can model sparse, noisy data, where other machine learning approaches fail. It has accelerated innovation in areas including alloys and component design, development of formulated products, drug discovery, additive manufacturing, and optimising chemical processes.

References

1. "Alchemite™ deep learning - solving complex problems with real-world data", Intellegens White Paper, 2021 [Online]. https://intellegens.com/alchemite-deep-learning-solving-complex-problems-with-real-world-data/

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