Machine Learning Assisted Induction Welding Simulations of Thick Unidirectional Carbon Fibre Reinforced Thermoplastic Polymer Laminates

NWC25
NAFEMS WORLD CONGRESS
19-22 MAY 2025 | SALZBURG | AUSTRIA
A WORLD OF ENGINEERING SIMULATION

This conference paper was submitted for presentation at the NAFEMS World Congress 2025, held in Salzburg, Austria from May 19–22, 2025.

Abstract

The aerospace industry is driving innovation in aircraft technologies and materials to achieve net-zero carbon emissions by 2050. This will require all aspects of the aircraft development, manufacturing, operation and disposal to be scrutinised. To develop fuel-efficient aircraft, integrate net-zero propulsion systems, and to allow for efficient recycling of material, Thermo-Plastic (TP) Carbon Fibre Reinforced Polymer (CFRP) is a promising construction material. Today'™s aircraft are typically constructed along assembly lines where components are joined. The new generation of net-zero aircraft will consist of multi-functional building blocks that require novel joining technologies. Furthermore, high volume assembly is key to support acceptance of more complex innovative aircraft concepts. TP-CFRP can be re-melted to allow for (dis-) assembly of aircraft components or sub-components. One technology that supports rapid assembly and disassembly of thermoplastic components is induction welding. Induction welding offers benefits like rapid contactless welding. However, effective heating of Uni-Directional (UD) TP-CFRP components is crucial for achieving a good quality weld but difficult to monitor and control. Furthermore, certification of induction-welded joints poses significant challenges, necessitating a deeper understanding of the welding process. Advanced 3D Finite Element Method (FEM) modelling can enhance this understanding and aid certification. At last, a good understanding and means of monitoring the welding process will support rapid assembly with minimum inspection intervals of the welding process. This paper presents an efficient and accurate FEM approach for induction welding of TP-CFRP laminates, capturing the multi-physics aspects of induction welding through a coupled electro-magnetic-thermal analysis. The induction heating and welding setup is modelled in detail, including a copper coil moving over a weld line with specific speed, distance, and amperage settings. The electromagnetic FE model accounts for the coil, air, and laminate, predicting the magnetic field and subsequent Eddy currents are generated in the conducting carbon fibres. The fibre orientation and interfaces between plies are explicitly modelled, as they significantly influence the formation of Eddy current loops. To enable real-time simulations for predictive purposes, the computationally expensive electromagnetic part of the simulation is replaced with a Machine Learning (ML) approach, more specifically Artificial Neural Network (ANN). The ANN predicts the 3D Joule heating fields in the TP-CFRP adherends, which are then used in the thermal FE model. The thermal model includes the laminate and accounts for natural convection and radiation. Accurate material characterisation is crucial for both the electromagnetic and thermal models. The induction heating model is validated through comparison with representative experiments, showing an accurate match. In this work the FEM approach is verified with physical experiments of static heating of UD TP-CFRP plates and dynamic heating of two plates forming a lap-joint. In addition, the methodology is extended to induction welding of thick UD TP-CFRP laminates up to 8 mm. By combining ML and physics-based modelling, this research enables the simulation-driven design and optimisation and real-time application of induction welding processes for UD TP-CFRP, reducing the need for physical prototyping and testing; and paves the way for a digital twin that can be used to monitor the induction welding process during manufacturing to support high volume assembly lines of innovative net-zero aircraft.

Document Details

Reference	NWC25-0006984-Paper
Authors	van Hoorn. N Koenis. T de Wit. B Vankan. J Maas. R Erartsin. O
Language	English
Audience	Analyst
Type	Paper
Date	19th May 2025
Organisation	NLR - Royal Netherlands Aerospace Centre
Region	Global

Download

Back to Previous Page

Stay up to date with our technology updates, events, special offers, news, publications and training

Subscribe (https://confirmsubscription.com/h/j/D3AC5A77B715D40B)

NAFEMS Membership

If you want to find out more about NAFEMS and how membership can benefit your organisation, please click below.

Joining NAFEMS (/join/)

(https://www.linkedin.com/company/nafems

(https://www.youtube.com/user/NAFEM

Cert No: [illegible]
ISO 9001