English Summary

Direct Energy Deposition (DED) processes are additive manufacturing processes that deposit metal in the form of wire or powder using an energy source with the same tool. The current TRL is evaluated in this work at 7. An industrial problem is:

How to establish production strategies for DED processes to improve their TRL?

The ANR METALIC project, in which this thesis is situated, aims to address this issue. A state-of-the-art review shows that the main cause of defects is poor thermal management of the processes. A major hypothesis of the manuscript is posed: mastering the thermal state would allow controlling the occurrence of defects during DED fabrication. Several strategies are identified to control this thermal state during production, and the implementation of thermal state feedback control is selected. The research question of the manuscript is:

What manufacturing strategy put in place in order to produce DED part first time right?

This work addresses this question within the following framework:

- Using the WAAM-CMT process,
- For an aluminum alloy,
- Studying only the deviation in weld beads thickness,
- For the fabrication of thin walls,
- In an environment compatible with industrial settings.

Four sub-research questions are proposed:

How to implement closed-loop control for DED processes? The definitions of the generic elements composing the DED machine and the software feedback control modules are proposed. These definitions are applied to a real WAAM-CMT system. The proposed software architecture supports this research by breaking the problem into independent sub-problems.

How to monitor the thermal state of DED processes? The state-of-the-art review shows that the thermal state can be characterized by an image of the NIR-SWIR thermal radiation of the aluminum melt pool. A NIR camera is chosen. The images are correlated with the variation of weld beads width. A comparison of different image processing techniques is proposed, and an image processing method based on neural networks is selected.

How to pilot the thermal state of parts during DED fabrication? Based on a state-of-the-art review, piloting the energy input of the DED tool is chosen to control the thermal state of the parts. A thermal control for WAAM-CMT process with an aluminum alloy is proposed and its effectiveness is demonstrated. The response times of this thermal control and the feedback loop are evaluated. They are in the order of seconds. The system's transfer function, from the command sent to the welding station to the prediction of width, is modeled by a first-order linear system.

How to control DED processes? A PID controller is chosen to control the process. Two cylinders are produced to validate the proposal: one with constant manufacturing parameters and the other with the proposed feedback control system. The system converges to the command, it is stable and it is robust against perturbation. The limitations of the system come from the feedback loop, which is based on neural networks. Neural network-based image processing produces a precise but untrue measurement, while conventional image processing provides a true but imprecise measurement.

The major contributions of this thesis are:

- A hypothesis based on the state-of-the-art: mastering the thermal state during DED fabrication allows for controlling manufacturing quality.
- An architecture for feedback control of DED processes.
- Thermal state monitoring for predicting weld bead width.
- Control of the process's thermal state.
- Identification of the limitations of neural networks.
- Thermal closed-loop control of the WAAM-CMT aluminum process.