Control of Distortions and Residual Stresses for the Repair of Parts by Additive Manufacturing Using Directed Energy Deposition

Context and Objectives

Additive manufacturing (AM) processes of the L-DED type (Laser Directed Energy Deposition), whether using powder or wire, are particularly suitable for repairing damaged or worn metallic parts. They are already used for turbine blade repair in the civil sector, and several national and European projects are currently focused on this topic. However, it remains very difficult to predict, optimize, and control the distortions and residual stresses introduced by these deposits in repaired parts, which are often complex in geometry. This represents a major obstacle to the qualification of repaired components. Three main scientific challenges explain this difficulty: (1) Macroscopic numerical models that are fast enough are often not predictive enough, (2) Microscopic models cannot be applied to full 3D part simulations because of their computational cost, even though this is essential in the repair context, (3) In-situ data and measurements needed to validate numerical approaches and control the process in real time across a wide range of parameters (e.g., laser power, scanning speed and strategy, use of the laser or argon flow for heat treatments during nozzle repositioning phases between layer depositions, etc.) are scarce.

The postdoctoral project is part of the LIDRES project ("Limiting Residual Distortions During Repairs by Additive Manufacturing"), funded by the Centre Interdisciplinaire d'Études pour la Défense et la Sécurité (CIEDS). This project aims to overcome the scientific barriers identified above. In-situ measurements using a 5-axis BeAM L-DED machine are currently being developed at the Laboratoire de Mécanique des Solides (LMS) and will be continued during the postdoctoral project. These will allow not only the validation of existing models under varied and complex conditions but also the establishment of real-time process control loops, thus addressing the third scientific challenge.

Research Topic

The first step will involve defining "academic" test specimens representative of the targeted structures (materials, types of repair zones, loading conditions). The goal is to design several geometries that will later serve for mechanical characterization tests. It will be essential to use 5-axis toolpath generation codes to prevent collisions between the deposition nozzle and elements of the part to be repaired. The tested and analyzed zones will typically be on the order of a few mm^2 to cm^2—small compared to real parts.

In a second phase, instrumented experiments (using a pyrometer, thermal camera, and visible camera) will be carried out on the BeAM powder-based DED machine at LMS. These experiments will enable multiscale measurements during the process (primarily local and/or global temperatures, displacements, and deformations) to recalibrate the models developed at LMS and within the LIDRES PhD project. After fabrication, the microstructures (repairs, interfaces) will be characterized and compared to the initial substrate. The residual stresses and distortions induced by the process will be estimated at various scales, in collaboration with BAM in Berlin [6]. As the project progresses, methods to reduce residual stresses during the process will be explored. Beyond global substrate heating—already investigated in the literature—local induction heating could be considered. Such localized thermal treatment could help control and minimize residual stresses.

At the end of the work, a repair will be performed on a so-called “technological” specimen, whose geometry will be based on a real part of interest. This specimen will serve as a demonstrator, confirming that the results obtained on “academic” specimens and through simulations can be scaled up to larger and more complex geometries.

Keywords

Additive manufacturing; repair; in-operando / in-situ measurements

Desired Profile

European nationality (for defense-related reasons). A PhD holder with significant experimental experience in thermo-mechanical processes. Interest in additive manufacturing processes is desirable, along with scientific rigor, curiosity, and strong autonomy. The recruited researcher will be primarily based at the Laboratoire de Mécanique des Solides (LMS), École Polytechnique, in Palaiseau (91), France.

Start Date

January 2026

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Compensation

Gross monthly salary: €3,300

References :

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